Foreign exchange intervention

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Publication date:
1995

Document Version
Publisher's PDF, also known as Version of record

Link to publication in Tilburg University Research Portal

Citation for published version (APA):
Almekinders, G. J. (1995). *Foreign exchange intervention: Theory and evidence*. [Doctoral Thesis, Tilburg University]. Elgar.

Foreign Exchange Intervention

Theory and Evidence

proefschrift

ter verkrijging van de graad van doctor aan de Katholieke Universiteit Brabant, op gezag van de rector magnificus, prof. dr. L.F.W. de Klerk, in het openbaar te verdedigen ten overstaan van een door het college van dekanen aangewezen commissie in de aula van de Universiteit op maandag 2 oktober 1995 om 16.15 uur door

Gerard Joost Almekinders

geboren op 5 september 1967 te Culemborg

Promotor:	prof. dr. J.J. Sijben
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Foreign Exchange Intervention

Theory and Evidence

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Edward Elgar

Published by
Edward Elgar Publishing Limited
Gower House
Croft Road
Aldershot
Hants GU11 3HR
UK

Edward Elgar Publishing Company
Old Post Road
Brookfield
Vermont 05036
US

British Library Cataloguing in Publication Data

Almekinders, Geert J.
Foreign Exchange Intervention: Theory and
Evidence
I. Title
332.4564

Library of Congress Cataloguing in Publication Data

Almekinders, Geert J., 1967–
Foreign exchange intervention: theory and
evidence / Geert J. Almekinders.
240p. 23 cm.
Includes bibliographical references and index.
1. Foreign exchange administration. 2. Foreign exchange rates.
3. Banks and banking, Central. I. Title.
HG3851.A46 1995 95–6824
332.4'5—dc20 CIP

ISBN 1 85898 263 4

Printed and bound in Great Britain by
Hartnolls Limited, Bodmin, Cornwall

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Acknowledgements

This book marks the completion of four years work in the Department of Economics at Tilburg University. Sylvester Eijffinger conceived the subject of this study which was carried out in the framework of a Ph.D. project. I am very grateful to him for supervising my thesis with ever-lasting enthusiasm and for co-authoring the papers which underlie Chapters 3-6 of this book.

The Deutsche Bundesbank, Hauptabteilung Ausland kindly provided the daily data on the official interventions of the Bundesbank on a confidential base. The Board of Governors of the Federal Reserve System, Division of International Finance kindly allowed Sylvester Eijffinger and me to use the daily data on the official interventions of the Federal Reserve System.

Tilburg University provided a stimulating academic environment and interesting colleagues. Frank de Jong, Bertrand Melenberg, Bruce Mizrach, Theo Nijman, Arthur van Soest and Marno Verbeek helped me with the econometrics in the book. Jacques Sijben made detailed comments on Chapters 2 and 7. Harry Huizinga, Eric Schaling and Alex Cukierman made some suggestions regarding Chapter 7.

The results of this study were presented at several seminars and conferences. I have benefited from the insights of seminar participants at the International Finance Division of the Board of Governors of the Federal Reserve System and at the Federal Reserve Bank of New York. Useful comments were made by delegates at the 1993 and 1994 Annual Conference of the European Economic Association and the 1994 Annual Conference of the Royal Economic Society. However, opinions and errors in the book are my own responsibility.

The results contained in this thesis have already appeared in several articles. Chapter 2 is an extended version of my 1994 article in *Kredit und Kapital*. Chapter 3 is a slightly updated version of a 1991 article in *Weltwirtschaftliches Archiv*. Chapter 4 is adapted from a 1994 article in *Empirical Economics*. The results contained in the appendix to Chapter 4 are taken from an article which has been accepted for publication in *Jahrbücher für Nationalökonomie*. Chapters 5, 6 and 7 of this book appeared earlier in the form of CentER discussion papers (nos 9444, 94101 and 9460, respectively).

I am grateful to the numerous tennis players who defeated me over the years and the soccer players who outplayed me. Unknowingly, they helped to convince me that my comparative advantage is in economics rather than in sports, which I often like to believe.

My parents and my brother deserve special thanks for their support.

1. Introduction

1.1 INTRODUCTION AND OUTLINE

In the early 1970s the Bretton Woods fixed exchange rate system was abandoned in favour of flexible exchange rates. Since then, the exchange value of the major currencies in the industrialized world is in principle determined by market forces. However, in the present system of managed floating the exchange rate is not the outcome of supply and demand by private exchange market participants only. The monetary authorities of many countries have frequently been trying to influence the relative value of their currencies by exchange market interventions.

It is often argued that the proper functioning of the global economy requires stable exchange rates. Yet, crucial exchange rates like the Deutsche Mark-US dollar exchange rate and the Japanese Yen-US dollar exchange rate experience recurrent cycles of appreciation and depreciation. In the 1970s and early 1980s the Group of 3 (G-3) countries Germany, Japan and the United States regularly resorted to individual *ad hoc* policy measures to stabilize exchange rates. The rather spectacular rise in the external value of the US dollar over the period 1983-85 led to a joining of forces. The Plaza Agreement of September 22, 1985 and the Louvre Agreement of February 22, 1987 entailed major changes in the coordination of exchange rate policies among the Group of 7 (G-7) countries.[1] Moreover, the establishment of these agreements marked a change in the frequency and volume of official exchange market operations conducted by the G-7 countries.

The aim of this book is to investigate the motives and constraints facing central banks when they decide to engage in foreign exchange intervention. The book is organized into eight chapters. The remainder of this first chapter gives a concise description of the foreign exchange market. Furthermore, it gives the definition of central bank intervention that will be used throughout the book. In addition, it discusses the exact implications of an operation in foreign currency by a central bank. Finally, it introduces the channels of influence of central bank intervention. Chapter 2 provides a comprehensive survey of theories on the scope for foreign exchange market intervention. The central question is whether and how non-sterilized and sterilized interventions are able to influence the course of the exchange rate. Chapter 3 surveys empirical studies which have been undertaken to assess which objectives the central banks of the main industrialized countries pursued with their interventions in the foreign exchange market. Moreover, this chapter reviews empirical studies which address the question of whether, in practice, (sterilized) intervention has been capable of exerting a significant influence on the exchange rate.

Chapters 4-6 abandon the traditional structural exchange rate models. The random-walk model or the GARCH model are used to investigate empirically the short-term objectives and effectiveness of daily interventions carried out by the Bundesbank and the Federal Reserve System over the period 1985-90. Estimation results reported in Chapters 4 and 5 indicate that both the Bundesbank and the Federal Reserve System conduct their foreign exchange operations consistently. However, the empirical evidence provided in Chapter 6 does not suggest that intervention conducted by the Bundesbank and the Federal Reserve was successful at systematically reversing unwanted movements in the DM/$ rate. The latter empirical result raises the question: why do central banks continue to intervene? Chapter 7 is an initial attempt to provide a positive theory of central bank intervention. It merges the insights derived from Chapters 4-6 together with the insights derived from the recent game-theoretic approach to monetary and fiscal policy.

To influence exchange rate movements interventions basically have to alter the balance of supply and demand for foreign exchange. However, average central bank transactions in foreign exchange are very small compared to the daily turnover on the world foreign exchange market. Furthermore, the central banks of most large industrialized countries commonly neutralize the money-market effect of their intervention operations. Therefore, these interventions, in essence, involve nothing but a shift in the currency composition of private investment portfolios. Consequently, it is unlikely that regular interventions have a significant effect on exchange rates. In Chapter 7 it is argued that the introduction of strategic behaviour by central banks can alter the scope for intervention rather dramatically.

It is a fact of observation that private exchange market participants are eager to detect any information related to official operations in foreign currency. Central bankers, in turn, know that their actions are monitored very carefully. Therefore, it seems to make sense to abandon the assumption — which is implicit to the majority of studies on exchange rate policy — that the central bank is regarded by private exchange market participants as 'just another exchange market participant'. Chapter 7 investigates the motives and constraints facing central banks when there is strategic interaction between the central bank on the one hand and private exchange market participants on the other hand. It analyses an exchange rate policy game between a central bank and rational speculators under symmetric information. The central bank tries to counteract shocks to the exchange rate by means of sterilized intervention working through the expectations channel. Private speculators resist being fooled. They anticipate the interventions. Chapter 7 studies the characteristics of the non-cooperative Nash equilibrium of the resulting exchange rate policy game. Propositions derived from the model are confronted with cross-country data. Moreover, attention is paid to the exchange rate policy game with unequal status of the players and to the game with asymmetric information of the central bank.

Chapter 8 provides a summary and concluding remarks.

1.2 THE FOREIGN EXCHANGE MARKET

At present, the currencies of countries in the Western world are freely exchangeable. This exchangeability or convertibility broadens the spectrum of available goods and financial assets enormously. For instance, residents of the United States are allowed to exchange US dollars for Japanese yen to buy cars manufactured in Japan. Furthermore, Japanese pension funds can exchange the contributions they receive in Japanese yen for US dollars to buy US government bonds.

In general, both international trade in goods and services and international capital flows lead to demand for and supply of foreign currencies.[2] Obviously, the growth of world trade depends on the international business cycle, i.e. the growth of world income. During the period 1970-93 the annual growth rate of the volume of world trade averaged 5.0 per cent. World trade growth in 1994 and 1995 is estimated at 7.2 and 5.9 per cent, respectively (IMF 1994). The global foreign exchange market would look rather tranquil if international trade in goods and services were the only source of demand for and supply of foreign currencies.[3] In those circumstances, countries' trade deficits and surpluses correct themselves through limited exchange rate adjustments. Take the United States as an example. As of 1983 the US dollar value of goods and services imported into the United States significantly exceeds the US dollar value of goods and services exported by the United States. In itself, the persistent trade deficit should lead to a drop in the external value of the US dollar. For, given the US trade deficit, non-residents selling goods and services to residents of the United States receive more US dollars than US residents receive foreign currencies in exchange for the goods and services they export. On the assumption that agents only want to hold the currency of the country in which they reside, an excess supply of US dollars will arise on the global foreign exchange market. In the case of freely floating exchange rates — which implies that central banks will not eliminate the excess supply of US dollars — the external value of the US dollar will fall. This raises the US dollar price of goods imported into the United States. At the same time, for non-residents the price of goods and services imported from the US becomes lower in terms of their own currency. Under normal circumstances, i.e. when the Marshall-Lerner condition holds, these price changes should be sufficient to restore equilibrium on the US trade balance eventually.

From the close of World War I until relatively recently, most countries' holdings of foreign assets have been limited both in quantity and scope. Over the last twenty years, however, financial markets have been liberalized significantly. In particular, international capital controls have gradually been abolished. Presumably, this is one of the driving forces behind the recent enormous growth of financial market turnovers in general and the surge in short-term international capital flows in particular. The enhanced international capital mobility regularly causes countries' current accounts of the balance of payments to be swamped by the capital accounts.[4] Consequently, in the recent past, the global foreign exchange market has only very seldom been a quiet place. Rather, the market looks hectic and out of control. The course of the DM/$ rate over the post-Bretton Woods period is depicted in Figure 1.1.

In general, institutional investors' holdings of foreign securities as a percentage of their total securities holdings rises year after year. Moreover, these international portfolios are managed very actively. In April 1992 the daily average of global spot market turnover net of double-counting arising from both local and cross-border interbank operations was estimated to be $400 billion. This implies a 15 per cent rise from the corresponding estimate of $350 billion for April 1989 (Bank for International Settlements 1993). To put these figures in perspective, in July 1993 the stock of foreign exchange reserves (excluding gold, IMF definition) of the G-10 countries was equal to $427.4 billion.[5] Due to the enormous magnitudes, even small changes in international capital flows can have profound effects on the world economy. Sharp gyrations in the Deutsche Mark/US dollar rate and the Japanese yen/US dollar rate in recent years can mainly be attributed to large portfolio shifts. The crises in the European Exchange Rate Mechanism (ERM) in the autumn of 1992 and in the summer of 1993 were caused by massive speculation.

In the aftermath of the first crisis in the ERM, at the IMF/World Bank

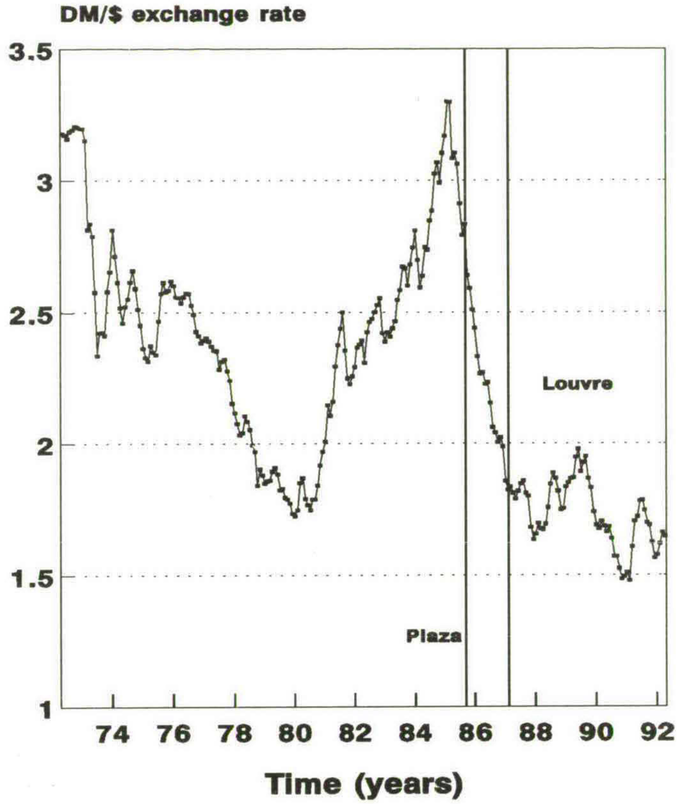

Figure 1.1 The exchange rate of one US dollar expressed in Deutsche Marks

Annual Meetings in September 1992, the Group of 10 agreed to undertake a study. The aim of this study was to get a better understanding of recent developments in international financial markets and their implications for the working of the international monetary system. Not surprisingly, the report states that

> close coordination and cooperation among countries on economic policies, particularly monetary and fiscal policies, continue to be an essential condition for exchange rates to be relatively stable. (Group of Ten 1993, p. 33)

In addition, it states that

> commitments to limit exchange rate movements lack credibility when market participants believe that prevailing exchange rates have become inconsistent with macroeconomic fundamentals. In such circumstances, efforts to defend exchange rates through official intervention risk draining the resources of the monetary authorities. However, when existing exchange rates are not clearly out of line with fundamentals, intervention to allow market participants time for reassessment, together with appropriate statements to reaffirm commitments by policy authorities, may be sufficient to defuse market pressures. This prospect is more likely when the authorities also demonstrate that they are prepared to adjust interest rates. In turn, the effectiveness of interest rate adjustments depends on how strongly market participants believe that the authorities will be willing and politically able to maintain interest rates at the adjusted level for a prolonged period, if necessary, to defend against exchange rate pressure. (Group of Ten 1993, p. 34)

The G-10 report partly draws on information gathered directly from private exchange market participants through a series of interviews conducted in each of the G-10 countries. On the whole, respondents thought that

> in the presence of major imbalances, intervention is ineffective unless accompanied by measures in other policy areas. (Group of Ten 1993, p. 34)

Still, it is common practice among central banks to neutralize the money-market effect of interventions. This is because monetary authorities usually do not want exchange rate policy to interfere with domestic monetary policy. The next section gives a definition of intervention and introduces the concept of sterilization.

1.3 CENTRAL BANK INTERVENTION

1.3.1 The definition of central bank intervention

Throughout the book a foreign exchange market intervention is defined as a sale or a purchase of foreign currency by the domestic monetary authorities which is explicitly aimed at changing the exchange rate of the domestic currency *vis-à-vis* one or more foreign currencies. For expositional purposes it will be assumed that in each country interventions are carried out by one official institution called the central bank.[6]

1.3.2 The effects of central bank intervention

The exact implications of an operation in foreign currency by the domestic central bank depend on who is the counterpart in the transaction. Here, a distinction will be made between the domestic non-bank private sector and the domestic commercial banking sector.[7] Throughout the analysis it will be assumed that in order to minimize forgone interest earnings every agent or institution in the domestic and foreign economy tries to minimize its holdings of non-interest-bearing checkable deposits irrespective of the currency of denomination. Furthermore, it is assumed that commercial banks are fully loaned up and that there is no such thing as a credit crunch.[8,9]

To analyse the effects of an official purchase of foreign currency consider first a simplified balance sheet of the domestic central bank.[10] A stylized balance sheet of the domestic central bank reflects that the monetary base of the domestic country (MB), which consists of total domestic currency in circulation and the reserves of the private banking system, is equal to the sum of net foreign assets (NFA) and domestic assets (DA) in the hands of the domestic central bank.

Assets	Liabilities
Net Foreign Assets (NFA)	**Monetary Base** (MB)
Gold	Total currency in circulation
Foreign currency	Reserves of commercial banks
SDR	
Net position in IMF	
Domestic Assets (DA)	
Government securities	
Loans to commercial banks	

Figure 1.2 Stylized balance sheet of the domestic central bank

Clearly, the primary responsibility of each central bank in the field of monetary policy is the provision of base money to the domestic economy, i.e. the domestic banking system. Expansionary monetary policy involves the offering of additional credit facilities by the central bank to the domestic banking system. These additional credit facilities, whichever way defined and arranged, add to the gross reserves of the domestic private banking system and to the gross domestic assets of the domestic central bank (Figure 1.3).[11]

To investigate the effects of an official purchase of foreign currency

Domestic central bank

Assets	Liabilities
Loans to commercial banks +	Reserves of commercial banks +

Domestic commercial banks

Assets	Liabilities
Reserves with the central bank +	Loans from central b. +

Figure 1.3 Expansionary monetary policy

Domestic central bank

Assets	Liabilities
Foreign currency +	Reserves of commercial banks +

Domestic commercial banks

Assets	Liabilities
Foreign currency +	Deposits of non-residents denominated in domestic currency +
Foreign currency –	
Reserves with the central bank +	

Figure 1.4 Official purchase of foreign currency from commercial banks

by the domestic central bank, suppose that non-residents are expecting the value of the domestic currency to rise. In the absence of any capital controls non-residents are free to acquire investments denominated in domestic currency. For instance, they may transfer their cash and bond holdings directly to domestic commercial banks. The top row in Figure 1.4 illustrates that banks obtain assets denominated in foreign currency. At the same time, their liabilities increase. However, the latter are denominated in domestic currency. In general, commercial banks are obliged (by the central bank) to limit their foreign exchange exposure. Therefore, they will enter the foreign exchange market as a net supplier of foreign currency, thereby putting the value of the domestic currency under upward pressure. The central bank may try to counteract the imminent appreciation of the domestic currency *vis-à-vis* the foreign currency by buying an amount of foreign currency. The purchase of foreign currency from the domestic commercial banks leads to the changes in the balance sheets shown in the bottom row of Figure 1.4. The central bank obtains the foreign currency. In return, the reserve position of the commercial banks is improved.

In sum, the intervention operation *ceteris paribus* leads to a smaller excess supply of foreign currency and hence to a smaller appreciation of the domestic currency. However, this does not go without a price. The domestic central bank has to tolerate a loosening of the domestic money market. By assumption, this will result in an increase in the domestic money supply. For that reason, it is sometimes argued that intervention carried out in this way amounts to using the foreign exchange market to conduct monetary policy in lieu of the domestic money market. Indeed, on comparing Figure 1.3 and Figure 1.4 it is clear that both an expansionary monetary policy and a purchase of foreign currency lead to a loosening of the domestic money market. In terms of the stylized balance sheet of the domestic central bank in Figure 1.2, monetary policy typically involves a change in the domestic monetary base brought about by the central bank through an open market purchase or sale of domestic government securities or by granting more or less credit to the commercial banks ($\Delta MB = \Delta DA$). The same change in the domestic monetary base can be effected by transactions in foreign currency ($\Delta MB = \Delta NFA$).

Above it was assumed that the expectation of an appreciation of the domestic currency leads foreign investors to transfer their money to domestic commercial banks. However, money from abroad may also flow to domestic non-banks (Figure 1.5).[12] The domestic non-banks are likely to pass on the foreign currency to the commercial banks who are by far the most prominent dealers on the foreign exchange market. In return, their domestic currency accounts will be credited.

Domestic central bank		Domestic commercial banks		Domestic non-banks	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
				Foreign currency +	Deposits of non-residents denominated in domestic currency +
		Foreign currency +	Deposits of non-banks +	Foreign currency — Deposits with the domestic commercial banks+	
Foreign currency +	Reserves of commercial banks +	Foreign currency — Reserves with the central bank +			

Figure 1.5 Official purchase of foreign currency from domestic non-banks with the commercial banks acting as intermediary

Domestic central bank		Domestic commercial banks	
Assets	Liability	Assets	Liability
		foreign currency +	Deposits of non-residents denominated in domestic currency +
Foreign currency +	Reserves of commercial banks +	Foreign currency — Reserves with the central bank +	
Government bonds denominated in domestic currency —	Reserves of commercial banks —	Reserves with the central bank — Government bonds denominated in domestic currency +	

Figure 1.6 Official sterilized purchase of foreign currency from domestic commercial banks

Consequently, the money stock in the domestic country increases directly. At the same time, the foreign exchange exposure of commercial banks is increased beyond what they regard as optimal. Presumably, the same sequence of events will occur as described above. The central bank is able to contain the rise in the value of the domestic currency. However, it has to accept a loosening of the domestic money market. Thus, in addition to the *direct* increase of the money stock which results from the inflow of money from abroad the domestic money stock increases *indirectly* due to the intervention undertaken by the central bank.

1.3.3 Intervention and sterilization

What stands out from the previous section is that the effects of purchases and sales of foreign currency by the domestic central bank are not limited to the reduction of changes in the exchange rate. An official purchase of foreign currency conducted to curb an appreciation of the domestic currency eventually leads to an increase in the domestic money stock. In Chapter 2 it will become apparent that the induced increase in the money supply in itself is very conducive to limiting the rise in the value of the domestic currency. However, since the middle of the 1970s central banks in the main industrialized countries implement monetary policy by targeting the growth rate of the money supply (Friedman 1975, Eijffinger 1986). The monetary authorities of these countries do not want exchange rate policy to interfere with monetary policy. Rather, they attempt to adhere to a preannounced target for the growth rate of some monetary aggregates. Gardner (1983) takes into account the notion that unsterilized interventions aimed at limiting exchange rate fluctuations in most instances frustrate attempts to realize preannounced targets for the money supply. Gardner assumes that central banks decide on an acceptable trade-off between the attainment of a target level of the money stock (M_t^T) and a target level of the exchange rate (S_t^T). The resulting loss function for a typical central bank (CB) can be written as follows:

$$L_t^{CB} = (M_t - M_t^T)^2 + c\ (S_t - S_t^T) \tag{1.1}$$

where L_t^{CB}, S_t and M_t are the loss of the domestic central bank, the exchange rate expressed as the domestic currency price of one unit of foreign exchange, and the money stock in the domestic economy; c is a non-negative parameter whose size depicts the relative weight attached to the two targets. This algebraic representation of the loss function misses the essential point. This is because monetary targeting can not be done in a half-hearted fashion. The central bank has to earn itself a reputation by realizing the preannounced target for a considerable number of years before the benefits of this policy can be reaped in the form of a lower expected rate of inflation and lower wage demands by the trade unions. Consequently, when the central banks adhere to certain monetary targets, the relevant value of c in the loss function is zero.

A central bank which wants to hit the target growth rates for monetary aggregates can deal with the international influences on monetary policy in two ways. First, it can choose to refrain totally from intervening in the foreign exchange market. In theory, one can think of a situation in which international capital flows leave domestic monetary policy unaffected. This is the case if, in addition to the no-intervention policy of the central bank, commercial banks in the domestic economy do not buy or sell foreign currency themselves but only act as currency brokers, i.e. when the net foreign assets of the domestic banking system remain constant over time. The money stock in the domestic economy is unaffected by international capital flows. Thus, monetary policy can be implemented to realize a reasonable degree of price stability. Under these circumstances, however, the exchange rate has to bear the full burden of adjustment. Any expected appreciation of the domestic currency which leads private exchange market participants to buy domestic currency leads to an actual appreciation of the domestic currency. Clearly, this can not be brought in line with the assumption made in the previous section that the central bank wants to take action against such expectations-driven appreciations of the domestic currency.

The second way to shield domestic monetary policymaking from international influences is to sterilize the money-market effects of official foreign exchange operations systematically. Clearly, the question of whether or not sterilized foreign exchange operations are effective is extremely important. Basically, it amounts to asking to what extent the central bank can have independent exchange rate and monetary targets. The answer has important implications for national authorities' conduct of their monetary policies and for IMF surveillance of its members' exchange rate policies.

Suppose, again, that there is an inflow of foreign currency into the domestic economy (top row of Figure 1.6). As a result, domestic commercial banks are entering the foreign exchange market as a net supplier of foreign currency. The central bank wants to counteract the imminent appreciation of the domestic currency. As before, it buys an amount of foreign currency (middle row of Figure 1.6). Now, however, at the same time it sells government bonds from its open market portfolio to the domestic commercial banks leaving the domestic monetary base, *ceteris paribus*, unchanged in spite of the initial purchase of foreign currency (bottom row of Figure 1.6).[13]

Clearly, the effect of an exchange market intervention on the monetary base is completely neutralized when $\Delta DA = - \Delta NFA$ in the stylized balance sheet of the domestic central bank. Sterilized intervention does, however, lower the initial excess supply of foreign currency in the foreign exchange market. Furthermore, sterilized interventions alter the currency composition of the entire, i.e. domestic and foreign, private sector's portfolio of investments. To see this, remember that the chain of transactions was initiated by non-residents selling financial assets, say bonds, denominated in their own currency because of a fall in the expected external value of their currency. These non-residents acquired bonds denominated in domestic currency.

In theory, the very change in the currency composition of investors' portfolios can make sterilized official purchases and sales of foreign currency have an effect on the exchange rate. This is the case if investors do not view otherwise identical bonds denominated in different currencies as perfect subsitutes.[14] For instance, suppose that investors are risk averse and that they demand a risk premium on bonds denominated in domestic currency (RP_t):

$$RP_t = (i_t - i_t^*) - (E_t\, s_{t+1} - s_t) \tag{1.2}$$

where i is the domestic interest rate, i^* the foreign interest rate, and s the logarithm of the spot exchange rate. Subscript t denotes time and $E_t(\cdot)$ is the expectations operator conditional on the information available at time t. Consider the effect of a disturbance of the portfolio balance caused by a sterilized purchase of bonds denominated in foreign currency carried out by the domestic central bank. The initial official purchase of foreign bonds causes an excess demand for these bonds. As a result, the price of these bonds rises and the foreign interest rate falls. The official sale of domestic bonds carried out to leave the monetary base in the domestic country unchanged induces an excess supply of domestic bonds. The price of these bonds falls and the domestic interest rate rises. However, these are mere mechanical reactions to changes in the supply conditions on the markets for both types of bonds. The sterilized purchase of foreign bonds carried out by the domestic central bank forces private investors *ceteris paribus* to hold more (relatively risky) domestic bonds in their portfolios. Consequently, the risk premium on domestic bonds demanded by private investors increases. This has important repercussions for the current exchange rate. In addition to the mechanical price changes of domestic and foreign bonds mentioned above, the expected rate of return on domestic bonds (i) has to rise relative to that

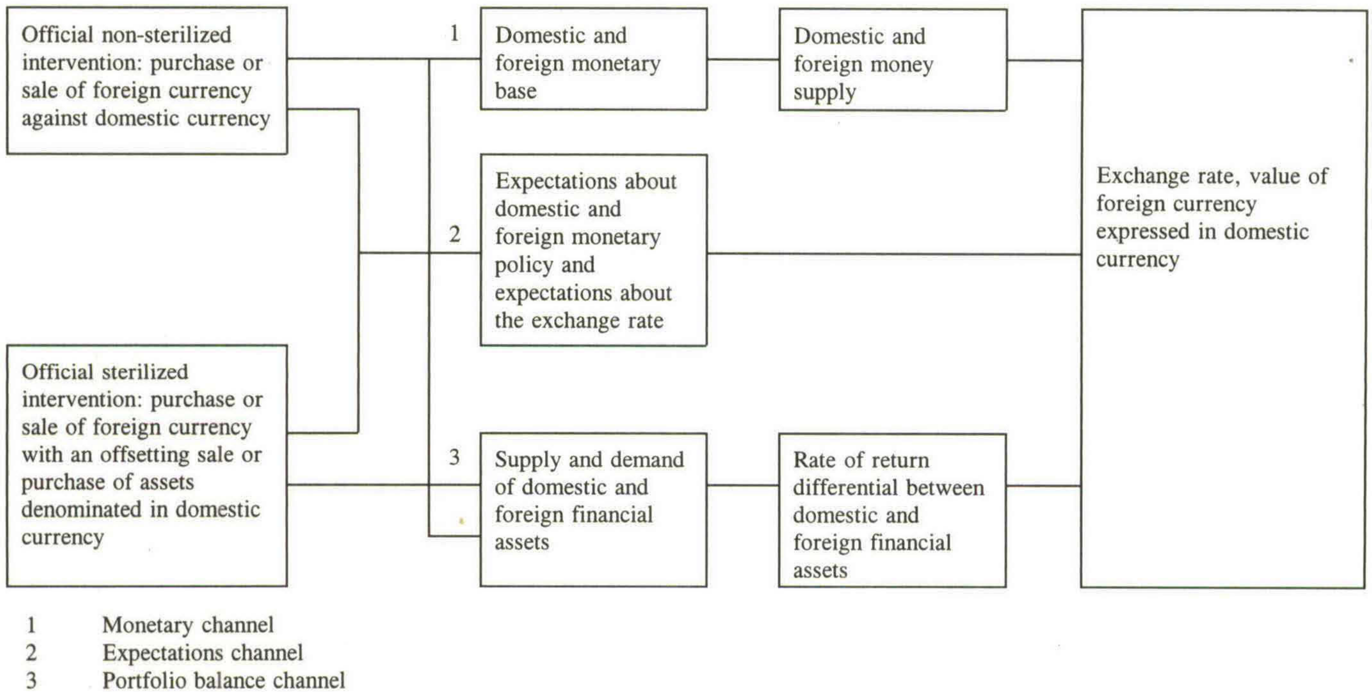

Figure 1.7 Three channels of influence of official intervention

on foreign bonds ($i^* + (E_t\, s_{t+1} - s_t)$) to enhance the attractiveness of domestic bonds. Thus, with the (longer-term) expected exchange rate ($E_t s_{t+1}$) assumed constant, the value of domestic currency has to decline initially (rise in s_t) in order to orchestrate an expected appreciation of the domestic currency. This will be termed *the portfolio balance channel* of (sterilized) intervention.

Loopesko (1984) distinguishes two other channels through which sterilized interventions can affect the exchange rate. The market-efficiency channel implies that the central bank can 'focus the attention of the public on neglected information that is germane to exchange rate determination' (Loopesko 1984, p. 258). Obviously, it will turn out to be very hard for the central bankers to establish the market inefficiencies with certainty. The superior-information channel corresponds with what will be called here *the expectations channel*. By providing the market with new information or a signal about the future course of the exchange rate or of monetary policy, the exchange rate can be expected to change immediately after the intervention. Notably, supporters of the asset-market view of exchange rates see this as the main channel through which interventions can affect the exchange rate. This channel is explored further in Section 2.3.2.

Figure 1.7 summarizes the three main channels of influence of central bank intervention.

NOTES

1. The Group of 7 consists of the following countries: the United States, the United Kingdom, Japan, Germany, Canada, France and Italy.
2. Strictly speaking, this is not necessarily the case. Agents may hold funds in the Eurodollar market and use these to invest abroad or buy foreign goods.
3. This seemingly imaginary situation was in fact approximated quite closely in the 1950s and 1960s when severe limitations to international capital mobility were in force.
4. This is one of the reasons why a systematic positive relation between trade balance surpluses and the external value of a currency can be observed only very rarely in practice.
5. The Group of 10 consists of the Group of 7 countries plus Belgium, the Netherlands and Sweden. Later on, Switzerland became the eleventh member of the Group of 10.
6. In several countries, e.g. Japan and the United States, both the central bank and the ministry of finance have a foreign exchange account that can be used for transactions in the foreign exchange market.
7. Obviously, in theoretical models without a fractional reserve private banking system this distinction is not relevant. In that case, the initial official operation in foreign exchange can only be carried out with 'the private sector' as the counterpart in the transaction.
8. A commercial bank is fully loaned up when it maximizes the amount of loans to third parties given the existing reserve requirements. If this is the case for all commercial banks in the economy then the mechanical money supply function applies ($M^S = m\ MB$, where M^S is the nominal money supply, m is the money multiplier which is assumed

constant and MB is the monetary base). Accordingly, an increase in base money (ΔMB) leads to an increase in the money supply (ΔM^S) by $m\ \Delta MB$.

9. The domestic country is said to experience a credit crunch when the non-bank private sector refrains from borrowing money from the banking sector in spite of a loose credit stance. This occurs when the non-bank private sector is restructuring its own balance sheet and hence tries to reduce its indebtedness to the banking sector (see, e.g. Kliesen and Tatom 1992).
10. As clearly put forward by Weber (1986), Belongia (1992) and Humpage (1994), intervention conducted by the domestic central bank almost necessarily involves the actions of the foreign central bank. For expositional ease and without loss of generality the present discussion concentrates on the effects of intervention on the domestic economy.
11. It may not be easy to trace such an operation in the actual balance sheet of a central bank. This is because the balance sheet reflects the institutional idiosyncrasies of the relation between the central bank and the private banking system in each individual country.
12. In cases when the domestic currency is expected to appreciate, internationally operating investors may acquire bonds denominated in domestic currency from domestic non-banks. Domestic enterprises can take up foreign currency loans abroad, exchange the proceeds for domestic currency and use this for the repayment of credit in domestic currency or for investment purposes. In addition, multinational enterprises are likely to shift their cash holdings to the domestic country.
13. Of course, the neutralization of the money-market effect of the initial purchase of foreign currency does not necessarily need to be effected by open market operations. What is essential for the separation of monetary policy from exchange rate policy is that employees at the central bank involved in the day-to-day management of the liquidity position of commercial banks view interventions as just another factor affecting this liquidity position which may be corrected if appropriate.
14. Pilbeam (1991, p. 38) lists three conditions for otherwise identical bonds denominated in different currencies to be imperfect substitutes. First, domestic and foreign bonds are perceived to have different degrees of riskiness due to uncertainty over expected real rates of return. Secondly, economic agents are risk averse. That is, investors only take on increased risk if there is a sufficient increase in expected returns to compensate. Finally, there must be a difference between the risk-minimizing portfolio and the actual portfolio forced at market-clearing prices into investors' portfolios.

2. Theories on the Scope for Foreign Exchange Intervention

2.1 INTRODUCTION[1]

The aim of this chapter is to provide a comprehensive survey of theories on the scope for foreign exchange market intervention. The central question is whether and how non-sterilized and sterilized interventions are able to influence the course of the exchange rate. To answer this question some well-established models of exchange rate determination are examined whereby focus is on the channels of influence of unsterilized and sterilized intervention in these models.

A distinction is made between flow models of the exchange rate on the one hand and asset-market models of the exchange rate on the other hand. These categories of models are treated in Sections 2.2 and 2.3, respectively. The left-hand column of Table 2.1 lists some representative flow and asset-market models of the exchange rate. For each of them a concise characterization is presented. This is followed by a review of articles which are primarily concerned with the mechanics of foreign

Table 2.1 Exchange rate models and 'intervention studies'

Exchange rate model	Non-sterilized intervention	Sterilized intervention
Purchasing Power Parity		
Mundell—Fleming model	Black (1985)	Black (1985)
Flex-price Monetary model		
Sticky-price Monetary model	Djajic & Bazzoni (1992)	Natividad & Stone (1990)
Portfolio Balance model	Moreno & Yin (1992)	Blundell-Wignall & Masson (1985)
Stock-flow Portfolio model	Branson (1983), Pilbeam (1991)	Hallwood & MacDonald (1986), Pilbeam (1991)

exchange intervention in the framework of the particular exchange rate model. The latter articles are listed in the two right-hand columns of Table 2.1.

Discontent with the performance of traditional structural exchange rate models in explaining the actual behaviour of exchange rates has led many economists to adopt new research strategies in exploring the field of exchange rate economics. Section 2.4 discusses some recent alternative approaches to the study of foreign exchange intervention which follow directly from these new research strategies. Section 2.5 concludes.

2.2 THE FLOW APPROACH TO EXCHANGE RATE DETERMINATION

2.2.1 Purchasing power parity

Purchasing power parity (PPP) is one of the earliest and simplest models of exchange rate determination. Still, it is a widely held view that PPP and hence the relative price of national outputs provides the international financial system with a long-term anchor for exchange rate movements. The absolute version of PPP relates the exchange rate of the foreign currency in terms of domestic currency to overall price levels in the domestic and foreign country. It is an extension of the well-known Law of One Price to general price levels.

At the going market exchange rate, the prices of identical goods at home and abroad expressed in one common currency may differ significantly. This will induce international trade-flows with goods being shipped from the cheaper country to the more expensive one. For example, suppose that foreign prices converted into domestic currency are lower than domestic prices. In that case the domestic country will experience a trade deficit. The domestic currency value of imports exceeds that of exports. Domestic residents demand foreign currency to pay for the imported goods. Foreign residents at the same time want to convert into foreign currency the revenues from selling their goods to domestic residents. Consequently, on the foreign exchange market an excess demand for foreign currency develops. The domestic currency depreciates until identical goods cost the same at home and abroad after converting prices to a common currency.

Accordingly, goods arbitrage eventually equalizes the market exchange rate to the PPP rate given by equation (2.1). Relative PPP is simply the concept of absolute PPP expressed in growth rates. Equation (2.2) asserts that the value of foreign currency in terms of domestic currency rises at a rate equal to the difference between domestic and foreign inflation.

Purchasing Power Parity

$$S_t = P_t \,/\, P_t^* \tag{2.1}$$

$$\dot{S}_t = \dot{P}_t - \dot{P}_t^* \tag{2.2}$$

$$M_t^{(*)}\, V_t^{(*)} = P_t^{(*)}\, Y_t^{(*)} \tag{2.3}$$

$$\dot{S}_t = (\dot{M} - \dot{M}^*)_t + (\dot{V} - \dot{V}^*)_t - (\dot{Y} - \dot{Y}^*)_t \tag{2.4}$$

where *S*, *P*, *M*, *V* and *Y* are the exchange rate (measured as domestic currency units per unit of foreign currency), the price level, the quantity of money supplied, the income velocity of money and real income, respectively. Subscript *t* denotes time. Foreign variables are denoted with an asterisk (*). A dot over a variable denotes a percentage change.

A different expression for the percentage change in the domestic currency value of foreign exchange can be obtained by combining the PPP relationship in equation (2.2) with the Quantity Theory of Money for both the home and the foreign country (equation (2.3)). With the income velocity of money and the level of real income unchanged, an increase in the domestic money supply will lead to higher domestic prices. Hence, the depreciation of the domestic currency (rise in S_t) implied by equation (2.4). It follows that an unsterilized intervention will in the long run, *ceteris paribus,* influence the level of the exchange rate. By contrast, a pure intervention which, by definition, lacks a money-market effect leaves the exchange rate unaffected.

In general, the validity of PPP is rejected in empirical tests (for a survey, see Giovannetti 1992).[2] A plausible explanation for the rejection of PPP is that in practice short-term capital flows swamp the trade balance of the balance of payments. It follows that exchange rates are primarily set in financial markets rather than in goods markets. Indeed, one observes that currency prices fluctuate day by day or even minute by minute whereas price levels are sticky and adjust slowly. With exchange rates moving more quickly than goods prices, deviations from PPP will arise. Therefore, exchange rates can persistently deviate from their PPP-implied values.

Particularly since the collapse of the Bretton Woods system of fixed but adjustable exchange rates a lot of effort has been devoted to investigating the determinants of short-term fluctuations in the exchange value of foreign currencies. Initially, most of these investigations were carried out along the lines of the Mundell—Fleming model.

2.2.2 The Mundell—Fleming model

2.2.2.1 The standard Mundell—Fleming model and intervention

Mundell (1963) and Fleming (1962) are seminal articles exploring the effects of monetary and fiscal policy under fixed and flexible exchange rates. They were written at a time when the Bretton Woods fixed exchange rate system was still operative. The theoretical framework underlying the analysis in the two studies has become known as the Mundell—Fleming model. Although it is not the primary aim of this model to explain exchange rate movements, it represents an authoritative formulation of the flow approach to exchange rate determination. An essential characteristic of the Mundell—Fleming model is that, after a shock has occurred, endogenous variables change so as to re-equilibrate supply and demand for foreign currency flowing through the balance of payments.

Mundell and Fleming consider a small economy which takes the world market price for traded goods and the world interest rate as given. In essence, the Mundell—Fleming model is a Keynesian model. Domestic output is demand determined and its price level is constant. Furthermore, wages are assumed to remain constant in domestic currency. There are four assets: domestic and foreign bonds, each having an identical maturity, and domestic and foreign currency. The bonds are assumed to be perfect substitutes. The currencies are assumed to be non-substitutable. Hence, they are only held in the country of issue.

According to equation (2.5), goods-market equilibrium obtains when the demand for the domestic country's output is equal to the supply. Here, the demand for the domestic good, D, is written as the sum of private sector real absorption, A, the trade balance, T, and government spending, G. Thus Y, domestic output, is determined by aggregate demand. Money-market equilibrium is defined in equation (2.6). The demand for money depends positively on domestic income and negatively on the domestic interest rate. Equation (2.7) reflects that, when the monetary authorities allow the exchange rate to float freely, the current account, T, and the capital account, C, sum up to zero. Implicit in the model is the assumption of static expectations. This implies *inter alia* that the expected exchange rate depreciation is equal to zero.[3] Consequently, a return differential between domestic and foreign bonds and hence net international capital flows can only arise through a difference between

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The Mundell—Fleming model[4]

$$Y = D = A(i,Y) + T(S,Y) + G \qquad A_i, T_Y < 0,\ 0 < A_Y < 1,\ T_S > 0 \quad (2.5)$$

$$M/P = L = L(i,Y) \qquad L_i < 0,\ L_Y > 0 \quad (2.6)$$

$$B = T(S,Y) + C(i) = 0 \qquad C_i = \infty \quad (2.7)$$

where D, A, T, G, L and C are the demand for domestic goods, private sector real absorption, the trade balance, government spending, real money demand and the capital account, respectively. The partial derivative of a variable X with respect to a variable Z is denoted as X_Z.

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the domestic rate of interest and the given world interest rate.

The familiar IS—LM analysis is usually conducted in i—Y spaced figures. However, S—Y spaced figures allow more scope to visualize the change in the exchange rate brought about by exogenous shocks. The IS schedule in Figure 2.1 connects combinations of domestic output and the exchange rate for which the goods market is in equilibrium. It is upward sloping. The marginal propensity to spend is assumed to be less than unity. Hence, an increase in domestic output leads to an excess supply of goods. A depreciation of the domestic currency is required to maintain equilibrium in the goods market. The LM schedule in Figure 2.1 maps out combinations of domestic output and the exchange rate for which the money market is in equilibrium. The LM schedule is vertical in S-Y space. For a given domestic interest rate there is only one income level compatible with money-market equilibrium.[5] Finally, the BP schedule traces out points for which the balance of payments is in equilibrium. It is upward sloping in S-Y space. However, it is less steep than the IS schedule to make sure that the system is stable. An increase in income causes the trade balance to deteriorate. This induces a depreciation of the domestic currency.

Imagine the domestic economy is initially at the equilibrium point A. We want to investigate the effect of an unsterilized purchase of foreign currency by the domestic central bank. However, domestic residents are assumed to hold only domestic money and domestic and foreign bonds. Without loss of generality we can proceed by investigating the effects of an unsterilized purchase of foreign bonds from the domestic non-bank private sector conducted by the domestic central bank. In Section 1.3.2 it

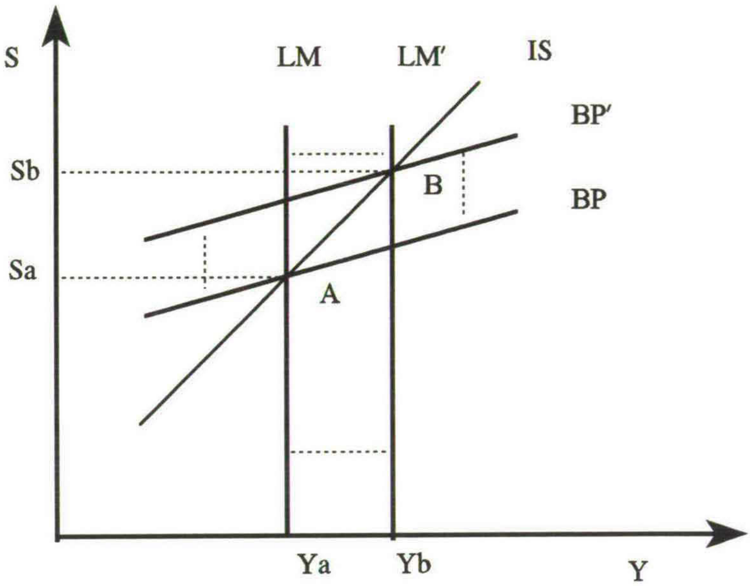

Figure 2.1 *The effect of an unsterilized purchase of foreign bonds by the domestic central bank in the Mundell—Fleming model*

was established that, as a direct consequence of this operation, the domestic money supply increases. On the assumption of static expectations and perfect international capital mobility the domestic interest rate is *de facto* fixed at the foreign level. Yet, the intervention operation can be thought of as causing an incipient decline in the domestic interest rate. This in turn leads to a capital outflow and a lower value of the domestic currency. The depreciation of the exchange rate improves the competitiveness of domestic industries and thus causes domestic income to rise. The vertical LM schedule shifts to the right while the BP schedule simultaneously shifts upward. The domestic economy settles down at the new equilibrium in point B.

Algebraic expressions for the relevant money multipliers confirm the insights derived from the graphical exercise. The multipliers can be written as follows:

$$\frac{dY}{dM}\Big|_{dB=0} = \frac{1}{L_Y} \succ 0$$

$$\frac{dS}{dM}\Big|_{dB=0} = \frac{1-A_Y-T_Y}{L_Y\,T_S} \succ 0$$

In Section 1.3.3 it was established that a sterilized or pure intervention results in a change in the currency composition of the private sector's nominal financial wealth but not in its volume. In the Mundell—Fleming model bonds denominated in different currencies are perfect substitutes. Consequently, the altered currency composition brought about by the sterilized intervention does not have any effect on the exchange rate.

2.2.2.2 (Un)sterilized intervention in Black's (1985) flow model

Not every author surrenders to the apparent ineffectiveness of sterilized intervention in flow models of the exchange rate. Black (1985) adopts a rather eclectic approach to model the exchange rate. Black combines some selected building blocks of the various models of exchange rate determination which survived in empirical testing. He argues that, in general, empirical evidence is not supportive of short-run PPP (see also Section 2.2.1) and perfect substitutability of assets denominated in different currencies.[6] Black assumes imperfect substitutability and rational expectations under imperfect information.

In essence, however, Black (1985) uses a flow model of the exchange rate to investigate the effectiveness of unsterilized and sterilized intervention. He starts out by deriving a short-run stock equilibrium condition for foreign assets. Within a mean-variance framework he derives an expression for the net stock of bonds denominated in foreign currency f_t private investors are willing to hold:

$$f_t = \beta\ [(E_t s_{t+1} - s_t) + (i_t^* - i_t)] \qquad \text{with} \qquad \beta = \frac{1}{\rho \sigma_{s,1}^2} \tag{2.8}$$

Accordingly, the willingness of speculators to hold foreign assets depends positively on the expected depreciation of domestic currency $(E_t s_{t+1} - s_t)$ and the excess of the foreign over the domestic interest rate $(i_t^* - i_t)$. It is inversely related to the variability of the exchange rate $\sigma_{s,1}^2$ and the investors' degree of risk aversion ρ. The first difference of the stock of foreign assets held by speculators in consecutive periods is taken to imply the out*flow* of private capital Δf_t (equation (2.9)). Equation (2.10) is the trade balance measured in foreign currency. Equation (2.11) accounts for changes in central bank reserves. The central bank intervention reaction function consists of two parts. Firstly, the 'leaning against the wind' component $(-\xi_1 (s_t - s_{t-1}))$ reflects that the central bank buys foreign currency (positive value of Δr_t) when the current exchange rate is lower than the exchange rate in the previous period. Secondly, the component capturing intervention aimed at driving the exchange rate closer to the target level s^T $(-\xi_2 (s_t - s^T))$ reflects that the central bank buys foreign currency (positive value of Δr_t) when the exchange rate is lower than this target level. Equation (2.12) is the balance of payments identity

Black's (1985) flow model of the exchange rate

$$\Delta f_t = \beta \, [\Delta \, (E_t s_{t+1} - s_t) + \Delta i_t^* - \Delta i_t] + v_t \tag{2.9}$$

$$t_t = \tau \, (s_t + p_t^* - p_t) + \epsilon_t \tag{2.10}$$

$$\Delta \, r_t = -\xi_1 \, (s_t - s_{t-1}) - \xi_2 \, (s_t - s^T) \tag{2.11}$$

$$\Delta \, r_t + t_t + \Delta \, f_t = 0 \tag{2.12}$$

where f_t and r_t are the stock of net foreign assets held by the private sector and the central bank, respectively; v_t and ϵ_t are uncorrelated random disturbance terms with mean zero, constant variance and zero autocorrelation; τ, ξ_1 and ξ_2 are positive constants; lower-case letters refer to natural logarithms of variables; Δ is the first-difference operator with $\Delta \, x_t = x_t - x_{t-1}$; E_t represents the expectations operator conditional on information available at time t.

under floating exchange rates.

Non-sterilized purchases of foreign currency increase the domestic monetary base and lower the domestic interest rate. In Black's model this leads to additional private purchases of foreign bonds. Consequently, the initial effect of central bank purchases on the balance of supply and demand in the foreign exchange market is strengthened. However, Black does not consider the monetary channel of intervention to be the most interesting one.

Black's analysis of the effectiveness of sterilized intervention is rather unusual. For him it is not the *direct* influence of intervention on the exchange rate that counts. This probably has to do with the fact that typical central bank intervention efforts are very tiny compared to the average daily turnover on foreign exchange markets. Black is in search of an *indirect* effect of sterilized intervention which has more leverage on the exchange rate. He looks for ways in which private investors can be made to support the central bank's actions aimed at limiting exchange rate movements. In Black's model private speculators have a stabilizing influence on the course of the exchange rate. They are assumed to be rational. Furthermore, they know the equilibrium value of the exchange rate. According to Black sterilized interventions are effective if they reduce uncertainty among investors (measured by $\sigma^2_{s,1}$). The lower risk induces private investors to assume a larger position in foreign currency. Hence, speculative capital flows, which are assumed to be stabilizing, are increased.

Based on the model described by the equations (2.9)—(2.12), which is quite similar to the one analysed in Neumann (1984), Black derives expressions for β, the willingness of speculators to bear risk. It should be noted that the author assumes the foreign interest rate to be constant. More importantly, sterilized interventions are assumed to leave the domestic interest rate unaffected. There are two types of *sterilized* intervention; 'leaning against the wind' intervention ($\xi_1 > 0$) and target intervention ($\xi_2 > 0$). Both types of intervention are found to reduce $\sigma^2_{s,1}$, the level of uncertainty about the exchange rate, and hence increase the volume of speculators' stabilizing position taking in foreign currency.[7] The underlying mechanism by which this is accomplished remains rather nebulous. Of course, the central bank's transactions in foreign exchange initially have a bearing on the flow equilibrium. The stabilizing impact of the official operations in foreign currency may remove part of the uncertainty among private speculators and hence strengthen the initial effect of the official transaction. However, the central bank is only a minor participant on the market for foreign exchange. A huge amount of intervention may be required to convince private market participants. Then, sterilization involves voluminous offsetting open market transactions. For instance, when the central bank initially buys foreign exchange from the domestic non-bank private sector to bring the exchange rate closer to the PPP level from below, sales of government bonds denominated in domestic currency are required to neutralize the money-market effect of the intervention. The price of domestic bonds will decline and the domestic interest rate will go up. Hence, the assumption of constant domestic and foreign interest rates, which is at the heart of the analysis of sterilized intervention in Black (1985), seems to be rather unrealistic. This raises doubts about the practical relevance of the reported effectiveness of sterilized intervention.

2.3 THE ASSET-MARKET APPROACH TO EXCHANGE RATE DETERMINATION

2.3.1 Introduction

The flow analysis according to Mundell—Fleming essentially views the exchange rate as the relative price of national outputs. The enormous growth of financial market turnovers in general and the surge in short-term international capital flows in particular cause a country's current account of the balance of payments to be swamped by the capital account. As a consequence, the exchange rate is more and more viewed as an asset price which is equal to the price of one national money in terms of another. Furthermore, according to this approach exchange rate changes are not caused by shifts in the typical demand and supply schedules for foreign exchange because of real transactions; changes in the perception of the market as a whole with regard to the value of one currency *vis-à-vis* one or more other currencies are the crucial factor.

2.3.2 The flexible-price monetary model

One branch of asset-market models of exchange rate determination assumes that wealth holders are indifferent as to the proportions of domestic and foreign currency-denominated assets in their portfolios given that they yield the same return expressed in one currency. In other words, in these models portfolio shares are infinitely sensitive to changes in expected rates of return. Hence, the perfect substitutability hypothesis implies that otherwise identical bonds denominated in different currencies can be viewed as one homogeneous asset. It follows that under risk-neutrality uncovered interest parity prevails (equation (2.15)). This implies that the interest rates on domestic and foreign bonds are equal unless there is an expected depreciation of the domestic currency. The world bond market always clears instantaneously. Furthermore, PPP is assumed to hold continuously (equation (2.16)). This implies that the real exchange rate and, thus, the relative price of domestic and foreign goods is constant over time due to perfect international arbitrage on the goods market. Consequently, in the flexible-price monetary model of the exchange rate demand and supply conditions on the markets for goods and bonds are irrelevant; in the short run a bilateral exchange rate is determined by the requirement of money-market equilibrium in the two countries involved whereby it is assumed that residents of each country only hold their own money (equations (2.13) and (2.14)).

Under the assumption of flexible prices, the equations (2.13)—(2.16) can be solved for the exchange rate. Intertemporal substitution obtains equation (2.17).[8] It states that the bilateral nominal exchange rate depends on the current and expected future values of relative money supplies and relative outputs in both countries. Thus, the flex-price monetary approach to the exchange rate predicts that an unsterilized purchase of foreign bonds from the domestic non-bank private sector conducted by the domestic central bank leads to a rise in the domestic currency price of foreign exchange. The purchase of foreign bonds causes the domestic money supply to increase. Through equation (2.13), The flexible-price monetary model

$$m = p + \phi y - \lambda i \tag{2.13}$$

$$m_t^* = p_t^* + \phi^* y_t^* - \lambda^* i_t^* \tag{2.14}$$

$$i_t = i_t^* + E_t[s_{t+1}] - s_t \tag{2.15}$$

$$s_t = p_t - p_t^* \tag{2.16}$$

$$s_t = \frac{1}{1+\lambda} \sum_{i=0}^{\infty} [\frac{\lambda}{1+\lambda}]^i E_t [(m_{t+i} - m_{t+i}^*) - \phi(y_{t+i}^* - y_{t+i})] \tag{2.17}$$

where ϕ (= ϕ^*) and λ (= λ^*) are the elasticity and the semi-elasticity of money demand with respect to income and the interest rate, respectively. Here these are assumed identical for both countries.

the inherent excess supply of money is wiped out by an instantaneous rise in the domestic price level. Equation (2.16) implies that the domestic currency price of foreign exchange goes up as a consequence of the initial unsterilized purchase of foreign bonds.

Furthermore, and perhaps more surprisingly, based on the expression in (2.17) some authors argue that sterilized intervention can alter the current exchange rate through what is called the *expectations channel of intervention*. Sterilized intervention can provide private exchange market participants with new information or a signal about the future course of monetary policy. The 'signalling hypothesis' was first proposed by Mussa (1981). Accordingly, a sterilized purchase of foreign bonds from the domestic private sector signals an expansionary *future* domestic monetary policy. As can be seen from equation (2.17), the expectation of a looser domestic monetary policy in the future will make the domestic currency depreciate and hence the exchange rate go up, even though the initial intervention's money-market effect is neutralized in the short run (see equation (2.17)).

The relevance of the signalling or expectations channel of sterilized intervention is not undisputed. Private exchange market participants will only pay attention to the signal embodied in the sterilized intervention when in the past a stable relationship has emerged with interventions leading changes in monetary policy aimed at some exchange rate objective. Whether this stable relationship exists and whether private exchange market participants pay attention to it is an empirical issue.[9] More importantly, for the signalling hypothesis to be valid central banks have to back up interventions with subsequent changes in monetary policy. In other words, current sterilized interventions predetermine the path of future money growth and hence interfere with monetary policy. The neutralization of the money-market effect of the initial intervention is limited to the short run. This does not exactly meet with the definition of sterilized intervention given in Section 1.3.3.

2.3.3 The sticky-price monetary model

2.3.3.1 The standard sticky-price monetary model and intervention

The assumptions underlying the flexible-price monetary model are not compatible with the persistent rejection of PPP in empirical tests (see Section 2.2.1). Dornbusch (1976) amends the flex-price monetary model to take account of the stickiness of goods prices observed in practice. In the resulting sticky-price monetary model goods prices initially do not respond to disturbances of the goods-market equilibrium.[10] The abandonment of short-run PPP requires an equation to explain the evolution of the price level. Dornbusch assumes that the price level adjusts in proportion to excess demand (equation (2.22)). This process continues until long-run PPP is restored (equation (2.23)).

Sticky-price Dornbusch (1976) model

$$m = p + \phi y - \lambda i \tag{2.18}$$

$$i = i^* + \dot{s}^e \tag{2.19}$$

$$\dot{s}^e = \theta (\bar{s} - s) \tag{2.20}$$

$$d = \delta (s - p) + \gamma y - \sigma i \tag{2.21}$$

$$\dot{p} = \pi (d - y) = \pi [\delta (s - p) + (\gamma - 1) y - \sigma i] \tag{2.22}$$

$$\bar{s} = \bar{p} - \bar{p}^* \tag{2.23}$$

Where a bar over a variable denotes a long-run value and π is a positive constant denoting the speed of adjustment in the goods market.

Dornbusch assumes that exchange market participants form their expectations regressively (equation (2.20)). This implies that the exchange rate is expected to close a fraction θ of the gap between the long-run exchange rate and the current exchange rate. The sticky-price model holds on to the hypothesis of perfect capital mobility and perfect substitutability of bonds denominated in different currencies (equation (2.19)). According to Walras' law the world market for bonds, thus constructed, is in equilibrium when the market for domestic goods and money are in equilibrium. The sluggishness of the prices of domestic goods implies a crucial difference between the flexible-price monetary model in the previous section and the current sticky-price monetary model. Continuous stock equilibrium on the financial markets requires the interest rate and the exchange rate rather than the domestic price level to bear the full burden of short-run adjustment.

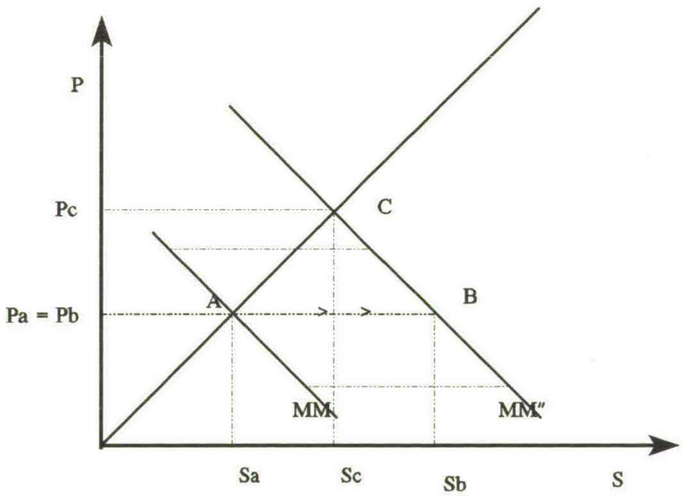

Figure 2.2 *The effect of an unsterilized purchase of foreign currency by the domestic central bank in the Dornbusch model*

Suppose the domestic economy is initially at the equilibrium point A. The MM schedule in Figure 2.2, which is essentially a long-run relationship, maps out combinations of the exchange rate and the domestic price level for which the money market is in equilibrium. It is downward sloping. For a given money supply a lower domestic price level causes real money balances to rise. In the long run, equilibrium in the money market is restored by a depreciation of the domestic currency which raises the demand for domestic goods and, thus, brings down real money balances through the induced rise in the domestic price level. Now consider the effect of an increase in the domestic money supply. The MM schedule shifts to the right. Furthermore, the long-run exchange rate and the domestic price level $(\bar{s}, \bar{p})$ will rise in proportion to the increase in the money supply. It follows that the new long-run equilibrium point C lies on the 45° ray passing through the origin, drawn in Figure 2.2.

The classical exercise in the Dornbusch model analyses the effect of a monetary expansion in the domestic country. This happens to be compatible with an unsterilized purchase of foreign currency by the domestic central bank. In the short run, with the domestic price level still unchanged, the intervention operation increases real money balances. According to equation (2.18) the immediate liquidity effect of the initial unsterilized purchase of foreign currency is to lower the domestic interest rate. The money-market effect of the intervention makes investors expect a long-run depreciation of the domestic currency. The decline in the domestic interest rate *plus* the expected depreciation of domestic currency seriously detract from the relative attractiveness of domestic bonds. Speculators want to be compensated for *both* factors. Consequently, the instantaneous restoration of goods and money-market equilibrium after the monetary shock requires the exchange rate to rise to the value associated with point B. Thereby it overshoots its long-run value in point C. The initial real depreciation (the exchange rate rises while the domestic goods price remains constant) and the lower domestic interest rate increase the demand for domestic goods (equation (2.21)). According to equation (2.22) this will cause domestic prices to rise. The economy gradually moves from point B to the new equilibrium point C.

In sum, with the price level sticky, the system can not jump to the new long-run equilibrium in point C. Instead, the exchange rate jumps, placing the domestic economy onto the stable path to the new long-run equilibrium (the MM'' schedule in Figure 2.2) along which the domestic price level rises and the domestic currency appreciates.[11]

The effectiveness of foreign exchange market intervention in both the flexible-price and the sticky-price monetary model depends crucially on its money-market effect. Once this is neutralized not a single economic variable in the model is affected by the intervention operation. This can be seen from the equations (2.18), (2.19), (2.20) and (2.23) above. Suppose the economy is initially in a steady state. This implies that the expected change in the exchange rate is zero ($\dot{s}^e = 0$). Consequently, from equation (2.20), the current exchange rate is equal to its long-run equilibrium value ($\bar{s} = s$). Due to the lack of a money-market effect, sterilized interventions do not alter the long-run equilibrium exchange rate $\bar{s}$. Hence pure interventions preserve the zero expected exchange rate change. Consequently, they leave the current exchange rate unchanged. Moreover, uncovered interest parity (equation (2.19)) implies that interest rates at home and abroad remain equal as well.

2.3.3.2 Unsterilized intervention in Djajic and Bazzoni (1992)

The effectiveness of monetary intervention in the sticky-price monetary model is undisputed. Djajic and Bazzoni (1992) modify the Dornbusch model to include a rule governing unsterilized foreign exchange market intervention (equation (2.24)). This rule describes the intervention behaviour of the monetary authorities in response to shocks to the exchange rate. Accordingly, the domestic money supply is brought down below the pre-disturbance level m_0 after the occurrence of a depreciation of the domestic currency which has raised the exchange rate above its pre-disturbance level s_0. The extent of the monetary contraction depends on the value of the policy-determined coefficient ω. Obviously, the polar cases $\omega = 0$ and $\omega = \infty$ are compatible with freely floating exchange rates and fixed exchange rates, respectively. Agents are assumed to be risk neutral, to know the structure of the model and to form their expectations rationally (equation (2.26)). Accordingly, the actual rate of depreciation $\dot{s}$ equals the expected rate of depreciation of domestic currency ($\dot{s}^e$). Hence, the uncovered interest parity condition can be written as in equation (2.27). With output fixed at the full employment level y, the change in the price level is given by equation (2.28), where ν is a shift parameter which reflects commodity-market disturbances.

It follows from the discussion of monetary intervention in the previous section that the greater the magnitude of unsterilized 'leaning against the wind' intervention, the greater the extent to which pressures on the domestic currency to fall (rise) in value, in response to, for example, an increase (decrease) in the foreign interest rate, are absorbed through a reduction in (an expansion of) the domestic money supply rather than a depreciation (an appreciation) of the domestic currency. Put differently, a move away from fixed exchange rates (i.e., a lower value of ω) allows for greater stability of monetary aggregates.

Djajic and Bazzoni stress that these are long-run considerations. They analyse the dynamic properties of the system in (2.24)—(2.28) for different values of ω, the parameter capturing the degree of 'leaning against the wind' intervention. The authors do not analyse the over- or undershooting of short-run exchange rates. Rather, their focus is on the evolution over time of the money stock as a function of the degree of 'leaning against the wind' intervention.

The crucial assumption in the Dornbusch model is that asset markets

Unsterilized intervention in Djajic and Bazzoni (1992)

$$m = m_0 - \omega (s - s_0) \qquad 0 \leq \omega \leq \infty \tag{2.24}$$

$$m = p + \phi y - \lambda i \tag{2.25}$$

$$\dot{s} = \dot{s}^e \tag{2.26}$$

$$i = i^* + \dot{s}^e \tag{2.27}$$

$$\dot{p} = \pi [\delta (s - p) + (\gamma - 1) y - \sigma i + \nu] \tag{2.28}$$

m_0 and s_0 are the pre-disturbance level of the domestic money supply and the exchange rate, respectively; ω is a policy-determined coefficient denoting the extent of 'leaning against the wind' intervention; ν is a shift parameter which reflects commodity-market disturbances.

and exchange rates adjust quickly relative to the goods market and the price of domestic output. A direct consequence of this assumption is that, in the face of shocks impinging on the domestic economy, jumps in the exchange rate are required to achieve short-run equilibrium in the goods and assets markets. It is not very likely that these jumps in the exchange rate are compatible with the objectives of the monetary authorities. Hence, intervention is called for. Djajic and Bazzoni examine the economy's adjustment to both a goods-market and an asset-market disturbance.

Initially, the economy is in a steady state. Consider the effect of an increase in the demand for exports, reflected by an increase in ν in equation (2.28). Firstly, under freely floating exchange rates ($\omega = 0$) the increased demand for exports simply leads to an instantaneous appreciation of the domestic currency which lowers exports to their original level. Secondly, in the case when the monetary authorities pursue a policy of 'leaning against the wind' ($0 < \omega < \infty$) they will partly resist the rise in the value of the domestic currency. Djajic and Bazzoni show that a jump in the money supply is required to bring the economy on the relevant stable path towards the new steady state. Along it, domestic prices rise according to equation (2.28). The rising price level increases the demand for money. The concomitant rise in the domestic interest rate (equation (2.25)) results in renewed upward pressure on the value of domestic currency (equations (2.27) and (2.28)). Due to the ongoing 'leaning against the wind' policy this is partly translated into a gradually loosening monetary stance. Thirdly, under fixed exchange rates ($\omega = \infty$) the increase in the demand for exports will set the economy on a path of gradually rising prices. Along this path to the new steady state the money supply must be increased in proportion to the increase in domestic prices to preserve the fixed exchange rate.

What stands out is the rather counter-intuitive finding of larger *short-run* movements in the nominal money supply under a 'leaning against the wind' policy than under fixed exchange rates. This result seems to be due mainly to the use of an asset-market model of exchange rate determination to analyse the effect of a real shock. This is fallacious while in asset-market models the exchange rate is essentially viewed as a monetary phenomenon. Djajic and Bazzoni argue that the increased demand for exports initially leaves the demand for money unaffected. Then, within the Dornbusch model, indeed there is no scope for an appreciation of the domestic currency. I would argue that flow models like the Mundell—Fleming model rather than asset-market models offer the appropriate framework to examine the implications of various exchange rate regimes for the short-run effects of goods-market disturbances. In the former models an increased demand for exports will cause an incipient appreciation of the domestic currency. Then, under fixed exchange rates the monetary authorities are obliged to ease the monetary stance immediately after the goods-market shock occurs. In fact, the easing of the money supply under fixed exchange rates is likely to be larger than under a 'leaning against the wind' policy. This contradicts the finding of Djajic and Bazzoni (1992).

The Dornbusch model does offer an appropriate framework to analyse the short-run effects of financial-market disturbances like an increase in the foreign interest rate. Thus, for the latter type of shocks the performances of different exchange rate regimes can be compared legitimately. The results presented by Djajic and Bazzoni for this *casus* are in line with intuition. A positive shock to the foreign interest rate induces a net outflow of capital. This leads to an (incipient) rise in the exchange rate. Official purchases of domestic currency by the domestic central bank lead to an instantaneous contraction of the money supply both under a 'leaning against the wind' rule for intervention *and* under fixed exchange rates.[12] Thus, Djajic and Bazzoni arrive at the plausible result that the reduction in the money supply in response to an increase in the foreign interest rate is larger under fixed exchange rates than under a regime of managed floating. This confirms that a move away from fixed exchange rates allows for greater stability of monetary aggregates.

2.3.3.3 (Partly) sterilized intervention in Natividad and Stone (1990)

In Section 2.3.3.1 it was established that the sticky-price monetary model does not provide any scope for the effectiveness of fully sterilized interventions. Still, it can be of interest to investigate the implications of a varying degree of sterilization. Natividad and Stone (1990) extend the original Dornbusch model to include separate policy functions for domestic credit and central bank foreign exchange reserves while allowing for variable sterilization. The intervention reaction function in equation (2.30) permits exogenous intervention (r_{EX}, where a positive value denotes a purchase of foreign currency by the domestic central bank) and endogenous responses to an observed gap between the contemporaneous and long-run equilibrium real exchange rate. The domestic credit reaction function in equation (2.31) allows for exogenous operations (c_{EX}, where a positive value denotes monetary expansion through an open market purchase of government bonds denominated in domestic currency by the domestic central bank), endogenous sterilization of a fraction w_1 of changes in the central bank's foreign exchange reserves and endogenous attempts to smooth deviations of the interest rate from its long-run equilibrium value. Equation (2.32) states that base money and, thus, the money supply is equal to the sum of domestic assets (c) and net foreign assets in the hands of the central bank ($r \equiv nfa^{CB}$). The interest parity relationship is quite similar to the equation determining the outflow of private capital in Black (1985) (see equation (2.8) above). The net stock of bonds denominated in foreign currency domestic residents are willing to hold is given by

$$f = nfa - nfa^{CB} = \beta \; [\; i^* - i + \dot{s}^e \;] \tag{2.29}$$

Thus, equation (2.29) accounts for the fact that a country's net foreign assets can be in the hands of the private sector *and* in the hands of the central bank ($nfa^{CB} = r$). Rewriting (2.29) leads to equation (2.35). When β goes to infinity, otherwise identical bonds denominated in different currencies are perfect substitutes and equation (2.35) reduces to the familiar uncovered interest parity relationship. Clearly, the model encompasses, as special cases, the monetary models and the portfolio balance model, which will be delt with in section 2.3.4. Real income is assumed to be demand determined in the short-run. Goods-market pressure which eventually results in price adjustment is measured by the gap between contemporaneous aggregate demand and long-run equilibrium income (equation (2.37)).

Natividad and Stone analyse the effects of three exogenous shocks: discretionary monetary policy (increase in c_{EX}), discretionary intervention (increase in r_{EX}) and a change in the foreign interest rate.

Intervention and variable sterilization in Natividad and Stone (1990)

$$r = r_{EX} - \xi\ [(s - p + p^*) - (\bar{s} - \bar{p} + \bar{p}^*)] \qquad (2.30)$$

$$c = c_{EX} - w_1 r + w_2\ (i - \bar{i}) \qquad 0 \leq w_1 \leq 1 \qquad (2.31)$$

$$m = h_1 c + h_2 r \qquad (2.32)$$

$$m^d - p = \phi y - \lambda i \qquad (2.33)$$

$$\dot{s}^e = \dot{s} \qquad (2.34)$$

$$i = i^* + \dot{s}^e - (1/\beta)\ (nfa - r) \qquad (2.35)$$

$$d = \delta\ (s - p + p^*) + \gamma y - \sigma i \qquad (2.36)$$

$$\dot{p} = \pi\ (d - \bar{y}) \qquad (2.37)$$

where *nfa*, f and r ($\equiv nfa^{CB}$) are the total stock of net foreign assets of the domestic economy, the stock of net foreign assets in the hands of the domestic private sector and the stock of net foreign assets held by the domestic central bank, respectively; c is the stock of domestic assets in the hands of the central bank; r_{EX} and c_{EX} are exogenous central bank purchases of foreign currency and domestic bonds, respectively.

They note that in the case of perfect substitutability between bonds denominated in different currencies and in the absence of sterilization ($w_1 = 0$), changes in monetary and exchange rate policy by the domestic monetary authorities have identical implications (see also Section 1.3.2). Furthermore, for the case of perfect substitutability they conclude that fully sterilized intervention has no effect in either the short or long run. This result was discussed at the end of Section 2.3.3.1. Natividad and Stone are able to show that the lower the degree of endogenous sterilization w_1, the larger the initial jump in the exchange rate after a discretionary intervention (positive value of r_{EX}). In other words, they find that the effect of an *ad hoc* policy measure by the central bank depends on the exact shape of its own mechanical reaction pattern. This is a rather strange result. It is due mainly to the implausible specification of the intervention reaction function. In particular, the role of discretionary intervention, r_{EX}, is unclear. The intervention reaction function already accounts for *endogenous* intervention in response to observed movements in the exchange rate. More interestingly, Natividad and Stone find that for a given discretionary purchase of foreign currency carried out by the domestic central bank a change in the degree of sterilization has an ambiguous effect on the degree of overshooting. This is because a lower degree of sterilization increases both the initial jump in the exchange rate *and* its new long-run equilibrium value.

2.3.3.4 Monetary targeting and unsterilized intervention

From the above expositions it appears that the scope for sterilized intervention is quite negligible whereas the effectiveness of unsterilized intervention is undisputed. Since the middle of the 1970s the central banks of many large industrialized countries implement monetary policies based on targeting the growth of the money supply. Genberg and Roth (1979) analyse whether the use of monetary aggregates as intermediate targets for the implementation of monetary policy is compatible with unsterilized intervention aimed at limiting currency movements. They argue that the variance of the exchange rate around an equilibrium level can be reduced only at the cost of an increase in the intra-year deviation of the money supply from the target level. Genberg and Roth divide a year into two periods. Within the framework of a simplified Dornbusch model of exchange rate determination they analyse the effect of a temporary increase in the foreign interest rate in the first period. The increase in the foreign interest rate causes a depreciation of the domestic currency. The monetary authorities may attempt to moderate the depreciation in period one by reducing the growth of the money supply in that period below the rate corresponding to the announced target for the first and second periods taken together. As a consequence of the commitment to an annual monetary growth target, in period two when the domestic and foreign interest rate are equal again, the domestic economy will experience a more-than-average growth of the money supply. Obviously, the stability of domestic income growth may be hampered by this increased variance of the money supply. Under the additional assumption of rational expectations a truly clear-cut picture emerges from Genberg and Roth's analysis. With a positive shock to the exchange rate occurring again in the first period, lowering the first period's growth of the money supply will not succeed at all in smoothing the value of the domestic currency. Private exchange market participants anticipate a compensatory increase in the second period's growth of the money supply and an accompanying depreciation of the domestic currency. The induced decrease in the demand for domestic currency exactly offsets (the effect of) the lower money supply in the first period. Thus, the exchange rate stabilization policy is not effective in the period in which the shock to the exchange rate occurs. Furthermore, the second period's increase in the money supply necessary to meet the annual target leads to a rise in the exchange rate. Genberg and Roth (1979, p. 538) conclude that 'exchange rate smoothing is detrimental to exchange rate stability and, a fortiori, to output stability'.

2.3.4 The portfolio balance model

2.3.4.1 The standard portfolio balance model and intervention

The asset-market models of exchange rate determination analysed hitherto assume domestic and foreign assets to be perfect substitutes. Portfolio balance models explicitly leave open the possibility that investors believe assets denominated in different currencies to have different risk characteristics. In addition, risk aversion on the part of investors implies that they want to be compensated for the higher perceived risk of holding foreign assets. Suppose foreign investors demand a nonzero risk premium on the domestic asset (RP^D). Then a wedge is driven between the expected rates of return on domestic and foreign bonds. The uncovered interest parity relationship no longer holds:

$$i = i^* + \dot{s}^e + RP^D \tag{2.38}$$

In a world in which bonds denominated in different currencies are imperfect substitutes, the requirement of continuous money- and bond-market equilibrium jointly determines the exchange rate and interest rates.

Branson, Halttunen and Masson (1977) present a basic small country portfolio model of the exchange rate. There are three assets: domestic and foreign bonds and domestic money. In accordance with the short-run nature of the model, accumulation of foreign bonds through current account surpluses is ruled out.[13] Furthermore, there is no interaction between the financial markets and the goods market. Therefore, the latter is not specified in the model. The demand for money (M), domestic bonds (B) and foreign bonds (F, expressed in domestic currency: sF) are assumed to depend upon wealth, the own rate of return and the cross rates whereby the rate of return on money is set to zero. Equation (2.42) is the wealth constraint. Equation (2.43) is the adding-up constraint. It states that the demand elasticities for domestic money and domestic and foreign bonds must sum up to one. Equation (2.44) reflects the assumption of static expectations. Equation (2.45) describes the small-country assumption. It implies that the foreign or world interest rate is fixed. Both B and F are taken to be short-term fixed-price assets to avoid the complications introduced by capital gains resulting from changes in interest rates. The three market equilibrium conditions (2.39)—(2.41) contain two independent equations in s and i, given the wealth constraint (2.42). Any pair of (2.39)—(2.41), with W substituted from (2.42) can be used to determine short-run equilibrium values for the exchange rate and the domestic interest rate. For our purposes, the equilibrium conditions for the money market and the market for domestic bonds are the relevant equations to be analysed.

A simple portfolio balance model for a small country

$$M = m\,(i,\ i^* + \dot{s}^e)\ W \qquad m_i < 0,\ \ m_{i^*} < 0 \tag{2.39}$$

$$B = b\,(i,\ i^* + \dot{s}^e)\ W \qquad b_i > 0,\ \ b_{i^*} < 0 \tag{2.40}$$

$$sF = f\,(i,\ i^* + \dot{s}^e)\ W \qquad f_i < 0,\ \ f_{i^*} > 0 \tag{2.41}$$

$$W = M + B + sF \tag{2.42}$$

$$m + b + f = 1 \tag{2.43}$$

$$\dot{s}^e = 0 \tag{2.44}$$

$$i^* = \bar{i}^* \tag{2.45}$$

The MM schedule in Figures 2.3A and 2.3B connects combinations of the exchange rate and the interest rate for which the money market is in equilibrium. It is upward sloping. An increase in the domestic interest rate lowers the demand for money. The excess supply of real balances in the domestic economy has to be wiped out. This is achieved through a depreciation of the domestic currency. The domestic currency value of foreign bonds rises due to the higher exchange rate. The induced wealth-effect is assumed to increase the demand for money. The BB schedule in Figures 2.3A and 2.3B maps out combinations of the exchange rate and the interest rate for which the market for domestic bonds is in equilibrium. It is downward sloping. An increase in the domestic interest rate makes domestic bonds more attractive. The demand for domestic bonds can only be brought back to its equilibrium level by means of an appreciation of the domestic currency which lowers wealth through a reduction in the value of foreign assets in terms of domestic currency.

In the framework of the portfolio balance model outlined above, the central bank of the domestic (small) country can not carry out an unsterilized purchase of foreign currency. This is because the domestic residents are explicitly assumed to hold only their own money. To bring down the value of the domestic currency, the central bank can buy bonds denominated in foreign currency in the open market. As there is no fractional reserve private banking system in the model it is sufficient to note that 'the private sector' is the counterpart in the open market operation.

Consider Figure 2.3A. Suppose that the economy is initially in the equilibrium point A. A monetary intervention involves an official purchase of foreign bonds in exchange for domestic money. It leads to an excess demand for foreign bonds and an excess supply of money. The MM schedule shifts to the right. For given levels of the exchange rate the domestic interest rate has to decline in order for the investors to willingly hold the available stock of money. The position of the BB schedule is unaffected by the open-market operation while the proportion of wealth held in the form of domestic bonds is unchanged. The new equilibrium is in point B where all three markets are in equilibrium. In

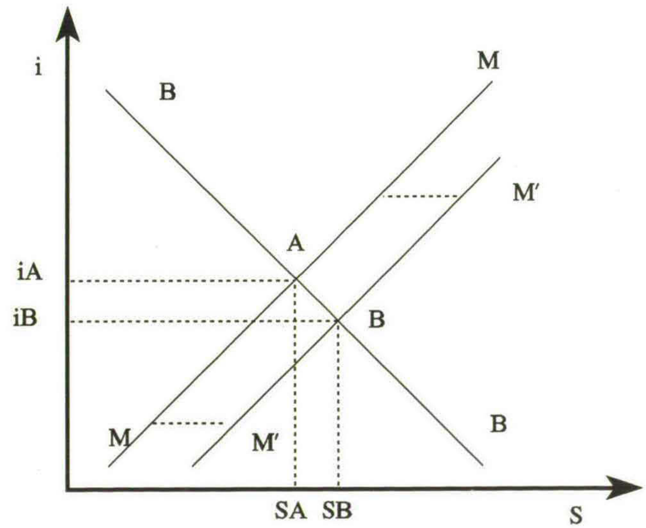

Figure 2.3A The effect of an official unsterilized purchase of foreign bonds in the small-country portfolio balance model

point B the interest rate is lower so as to clear the excess supply of money (substitution effect). The value of foreign currency is higher in order to bid up the proportion of wealth held in the form of foreign bonds (wealth effect).

The effect of an unsterilized intervention in the framework of the portfolio balance model is rather straightforward, as is the case in other models of exchange rate determination. It neither depends crucially on the small-country assumption nor on the assumption of static expectations nor on the degree of substitutability between domestic and foreign bonds. The picture changes when one considers the effect of a sterilized intervention in the framework of the portfolio balance model. Assume, again, that the simple model presented above in equations (2.39)—(2.45) gives a good description of the domestic economy's financial sector. Suppose that the domestic central bank wants to bring down the value of the domestic currency without altering the domestic money supply. To do so, it can buy foreign currency-denominated bonds from the private sector and at the same time sell domestic currency-denominated bonds to the private sector, leaving total private sector wealth unchanged. How exactly are investors going to react given that their portfolio shares are not infinitely sensitive to changes in expected rates of return on domestic and foreign bonds?

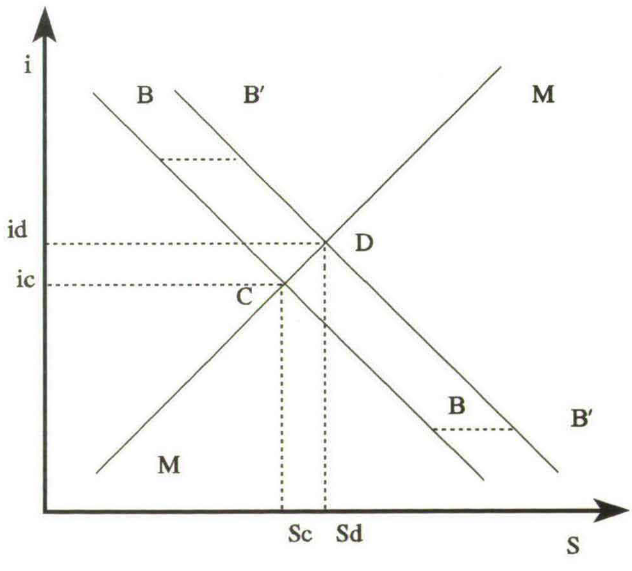

Figure 2.3B The effect of an official sterilized purchase of foreign bonds in the small-country portfolio balance model

Consider Figure 2.3B. Suppose the economy is initially in equilibrium in point C. A swap of domestic bonds for foreign bonds in the portfolio of the private sector leads to an excess supply of domestic bonds and an excess demand for foreign bonds. The money market remains in equilibrium with both the money supply and total private sector wealth unchanged. Thus, the BB schedule shifts to the right while the MM schedule is unaffected by the sterilized intervention. In the new equilibrium, point D, the domestic interest rate is higher, clearing the excess supply of domestic currency-denominated bonds. The value of foreign currency is higher. This bids up the proportion of wealth held in the form of foreign bonds. As a result the initial excess demand for foreign currency-denominated bonds is wiped out. In sum, the sterilized purchase of foreign bonds in exchange for domestic bonds carried out by the domestic central bank leads to a depreciation of the domestic currency.

Many authors find it hard to clarify the underlying mechanism by which a sterilized or pure intervention alters the exchange rate. This is the case particularly when the assumption of static expectations and the small-country assumption are dropped. The excess demand (supply) for (of) foreign (domestic) bonds causes the price of these bonds to rise (fall) and, hence, causes the foreign (domestic) interest rate to fall (rise). Obviously, these interest rate changes make domestic bonds relatively more attractive than foreign ones. However, they are mere mechanical reactions to changes in the supply conditions on the markets for both types of bonds. According to Henderson and Sampson (1983), given imperfect substitutability, investors require an additional inducement to switch their foreign bonds for domestic bonds. This relates to the third condition for imperfect substitutability as listed by Pilbeam (1991, p. 88).[14] Risk-averse economic agents may perceive otherwise identical bonds denominated in different currencies to have different degrees of riskiness. Yet these agents do not require a risk premium on the relatively risky asset as long as they can hold the portfolio of available financial assets which minimizes risk. A nonzero risk premium comes to the fore once there is a difference between the risk-minimizing portfolio and the actual portfolio forced at market-clearing prices into investors' portfolios. Assume that investors hold the risk-minimizing portfolio before the central bank engages in sterilized intervention. The sterilized purchase of foreign bonds carried out by the domestic central bank forces private investors to hold more (relatively risky) domestic bonds in their portfolios than what is optimal from a risk-minimizing point of view. Consequently, private investors demand a risk premium on domestic bonds. This has important repercussions for the current exchange rate. This can be seen by reasoning along the lines of the uncovered interest parity relation adjusted for a risk premium in equation (2.38). The mechanical price changes of domestic and foreign bonds due to changes in the supply conditions on the respective markets were mentioned above. In addition to these price changes the expected rate of return on domestic bonds (i) has to rise relative to that on foreign bonds ($i^* + (E_t s_{t+1} - s_t)$) to enhance the attractiveness of domestic bonds. Thus, with the (longer-term) expected exchange rate ($E_t s_{t+1}$) assumed constant, the value of domestic currency has to decline initially (rise in s_t) in order to orchestrate an expected appreciation of the domestic currency.[15]

2.3.4.2 Unsterilized intervention in Moreno and Yin (1992)

Until now, the effectiveness of unsterilized intervention working through the monetary channel is undisputed. Moreno and Yin (1992) come up with some new theoretical insights. Moreno and Yin draw on the experience of Taiwan in the 1980s. The monetary authorities in Taiwan tried to limit fluctuations in the New Taiwan (NT) dollar/US dollar exchange rate.

The authors develop a small open economy portfolio model with flexible prices. There are three assets: domestic money (m), domestic bonds (b) and foreign bonds (f). The real demand for each of these assets is a function of the nominal return on domestic bonds, the expected rate of depreciation of the domestic currency ($E_t s_{t+1} - s_t$), real wealth (w) and real income (y). The small-country assumption implies a fixed foreign interest rate. In the model it is normalized to zero. Central to the analysis by Moreno and Yin are the reduced form responses of the exchange rate and the price level to exogenous shocks *viz.* changes in the expected rate of depreciation of the domestic currency ($\Delta(E_t s_{t+1} - s_t)$) and changes in the supply of domestic money (Δm_t) and foreign bonds (Δf_t).

$$\Delta s_t = s_s \Delta(E_t s_{t+1} - s_t) + s_m \Delta m_t + s_f \Delta f_t, \qquad s_s > 0,\ s_m > 0,\ s_f < 0 \quad (2.46)$$

$$\Delta p_t = p_s \Delta(E_t s_{t+1} - s_t) + p_m \Delta m_t + p_f \Delta f_t, \qquad p_s > 0,\ p_m > 0,\ p_f < 0 \quad (2.47)$$

Moreno and Yin trace out the effect of a shock to exchange rate expectations. An expected appreciation of domestic currency ($\Delta(E_t s_{t+1} - s_t) < 0$) increases the demand for assets denominated in domestic currency. As a result, the domestic currency appreciates (equation (2.46)). The authors analyse the extent to which the central bank is able to neutralize this appreciation by conducting unsterilized purchases of foreign bonds. The intervention operation leads to an increase in the domestic money supply and a simultaneous reduction in the supply of foreign assets held by domestic residents of equal magnitude. As a result, the initial appreciation of domestic currency is reversed (at least partly, depending of the extent of 'leaning against the wind' intervention). The authors arrive at the familiar insight that the domestic central bank can limit exchange rate changes to any desired degree. However, this occurs at the cost of larger changes in the central bank's holdings of net foreign assets and, hence, in the domestic money supply.

Moreno and Yin point out that the story does not necessarily end here. The exchange rate change to which the central bank reacts was initiated by a shock to private investors' exchange rate expectations. In the terminology of the authors the intervention outcome is credible when investors believe that, after the unsterilized or monetary intervention in reaction to the expectations-induced change in the exchange rate, there will be no further change in the exchange rate. By contrast, the outcome of intervention is not credible when investors 'believe that the exchange rate must ultimately adjust to some target exchange rate s^*, regardless of the short-run attempts of policymakers to prevent such adjustment' (Moreno and Yin 1992, p. 20). Of course, when the central bank refrains from intervening, the full impact of a shock to expectations is felt immediately and the exchange rate adjusts to the equilibrium level s^* that private exchange market participants have in mind. Now, Moreno and Yin come up with a case in which unsterilized 'leaning against the wind' intervention is not effective. It only leads to a distribution over time of the impact of the one-time shock to expectations at the cost of higher cumulative intervention. It is important to note that this result hinges on the assumption that the expectation of an appreciation of domestic currency persists as long as $s > s^*$. Consequently, any intervention which initially prevents the exchange rate from reaching s^* leads to renewed excess demand for assets denominated in domestic currency.

At first sight, the persistence in the appreciation expectation does not seem very plausible. The unsterilized interventions lead to an increase in the domestic money supply and this will eventually lead to a rise in domestic inflation and hence to a *depreciation* of the domestic currency. Moreno and Yin come up with an interesting explanation. The appreciation expectation for the NT dollar was due to the competitive advantage of Taiwan's tradeables sector over that of other countries. Taiwan's growing exports indeed caused upward pressure on the external value of the NT dollar. Moreno and Yin argue that in the short run, unsterilized intervention can prevent equilibrium exchange rate adjustment. This may result in a sequence of growing trade surpluses for the domestic country. At the same time, investors may revise their estimates of s_t^* downward when confronted with news indicating no reduction in the trade surplus or complaints by trading partners.[16] It can readily be seen from equation (2.47) that there are two channels through which an unsterilized purchase of foreign bonds in exchange for domestic money leads to an increase in the domestic price level. Firstly, the intervention creates an excess supply of money.[17] Secondly, the central bank's purchase of foreign bonds creates an excess demand for foreign bonds by private investors. This leads to a depreciation of the domestic currency and, hence, to a higher domestic price level.[18] However, the recurrent updating of appreciation expectations has a deflationary effect.[19] Consequently, in the present case the increase in the money supply which results from unsterilized intervention is associated with a less than proportional increase in inflation. The innovations in the appreciation expectation hamper the adjustment process as described in Section 1.3.2 and prevent the working of the monetary channel of intervention. Moreno and Yin conclude from their analysis that the persistent and accelerating appreciation of the NT dollar in the 1980s may have been related to government efforts to limit such appreciation, which lacked credibility.

2.3.4.3 Sterilized intervention in Blundell-Wignall and Masson (1985)
Blundell-Wignall and Masson (1985) extend the sticky-price monetary model to allow for imperfect substitutability between assets denominated in different currencies. Equation (2.52) reflects that domestic investors demand a risk premium on foreign assets which depends positively on the privately held stock of net foreign assets ($nfa - nfa^{CB} = nfa - r$). Blundell-Wignall and Masson assume that the central bank systematically tries to resist movements in the real exchange rate away from a publicly known constant long-run equilibrium value. According to equation (2.49), the central bank enters the foreign exchange market to buy domestic currency ($\dot{r} < 0$) when the current real exchange rate is above its long-run value $\overline{s}_R$ ($\xi_1 > 0$). Furthermore, the central bank tries to prevent the stock of reserves from deviating from some target level $\overline{r}$. According to equation (2.55), the current real exchange rate may differ from its equilibrium level either because real interest rates differ at home and abroad or because private net claims on foreigners are nonzero. Obviously, sterilized purchases of foreign bonds affect the volume of privately held net claims on foreigners and, hence, have a bearing on the current real exchange rate through the portfolio channel described at the end of Section 2.3.4.1. Blundell-Wignall and Masson establish that the model is stable whatever the value of the intervention parameter ξ_1. It follows that the rule for sterilized intervention in equation (2.49) allows the monetary authorities 'to guide the exchange rate toward its long-run equilibrium value without inducing short-run fluctuations in that rate' (Blundell-Wignall and Masson 1985, p. 140).

From equation (2.51) it appears that private exchange market participants either do not anticipate the intervention behaviour or, if they

Sterilized intervention in Blundell-Wignall and Masson (1985)

$$s_R = s - p + p^* \tag{2.48}$$

$$\dot{r} = \xi_1 (\bar{s}_R - s_R) + \xi_2 (\bar{r} - r) \tag{2.49}$$

$$m = p + \phi y - \lambda i \tag{2.50}$$

$$\dot{s}_R^e = \theta (\bar{s}_R - s_R) \tag{2.51}$$

$$i = i^* + \dot{s}^e - (1/\beta)(nfa - r) \tag{2.52}$$

$$d = \delta s_R + \gamma y - \sigma (i - \dot{p}^e) \tag{2.53}$$

$$\dot{p} = \pi (d - \bar{y}) + \dot{p}^e \tag{2.54}$$

$$s_R = \bar{s}_R + [(i^* - \dot{p}^{*e}) - (i - \dot{p}^e)]/\theta - (nfa - r)/\theta\beta \tag{2.55}$$

do, consider it has no effect. To correct for this feature, Blundell-Wignall and Masson modify the model so as to let expectations correctly take account of intervention. With fully rational expectations regarding the exchange rate, equation (2.51) reduces to $\dot{s}^e = \dot{s}$ and equation (2.52) can be rewritten as $\dot{s} = i - i^* + (1/\beta)(nfa - r)$. The authors show that the resulting model has the saddlepoint property. Furthermore, they find that for a sufficiently high value of the intervention parameter ξ_1, sterilized intervention does not lead to cyclical fluctuations in the exchange rate.

The original Dornbusch model accounts for nominal exchange rates overshooting their long-run value in response to an increase in the domestic money supply. With prices sticky in the short run, the real exchange rate also overshoots. The mechanics of sterilized intervention in the amended sticky-price monetary model of Blundell-Wignall and Masson are not entirely clear. Shocks cause short-run misalignments of the real exchange rate. However, they leave the long-run equilibrium value $\bar{s}_R$ unaffected. Sterilized intervention, supposedly working through the portfolio balance channel described in Section 2.3.4.1 is said to 'speed up adjustment to past shocks' and to 'help lessen overshooting' (Blundell-Wignall and Masson, 1985, p. 142).

2.3.5 Stock-flow interaction in portfolio models of the exchange rate

2.3.5.1 Introduction

The portfolio model discussed in Section 2.3.4.1 is essentially a short-run asset-market model. There is no interaction between the asset markets and the goods market. Furthermore, in accordance with the short-run nature of the model accumulation of foreign assets through current account surpluses is ruled out. In the previous sections changes in the exchange rate were governed by the requirement of stock equilibrium. In the next sections it will become clear that the instantaneous adjustment of the exchange rate induces changes in the current account and capital account of the balance of payments. Thus, beyond the short run the course of the exchange rate is determined by flows of foreign exchange through the balance of payments.

Assume that before a shock occurs the trade balance, the capital income account and the capital account of the domestic economy are all individually in equilibrium. An exogenous fall in the exchange rate turns the trade balance and, by assumption, the current account of the domestic economy in surplus. As a consequence, the domestic private sector starts accumulating net foreign assets. Below, it will become clear that the exchange rate moves until the current account and the capital account are again individually in equilibrium.

2.3.5.2 Seminal work by Dornbusch and Fischer (1980)

Dornbusch and Fischer (1980) is a seminal article on long-term adjustment processes and the concomitant interaction between flows of foreign exchange and the dynamics of asset stocks. Dornbusch and Fischer assume that domestic economic agents can hold only domestic money and foreign bonds. Prices of goods produced in the small domestic economy are flexible. The prices of imports and the foreign interest rate are given. Domestic production is given and constant. The market for domestic goods is in equilibrium when domestic production equals the sum of domestic demand and net exports. The authors postulate an economy without a government sector, taxes or investment. Then, the excess of disposable income (which is equal to the sum of domestic production and net interest earnings from abroad) over spending is equal to saving and, due to the lack of investment opportunities in the home country, also equal to the accumulation of foreign assets. In turn, the level of savings is a decreasing function of real wealth. The mechanics of adjustment in this model can be highlighted by analysing how the domestic economy adjusts to a new long-run equilibrium after an initial current account surplus in period t caused by an exogenous change in, for instance, tastes or technology. The deficit on the capital account which accompanies the current account surplus leads to an increase in domestic real wealth through the accumulation of foreign bonds. The demand for money is assumed to depend positively on the net position in foreign assets. A fall in the domestic price level wipes out the excess demand for money. The lower price level leads to a further increase in real wealth. As real wealth is a determinant of domestic spending, the demand for domestic goods is increased. A restoration of domestic goods-market equilibrium requires the relative price of domestic goods to increase. With the domestic price level falling due to the real balance effect just described this necessitates an appreciation of the domestic currency which lowers the price of foreign goods expressed in domestic currency. Over time, the economy converges to a new equilibrium. On the one hand, the lower exchange rate mitigates the initial current account surplus. On the other hand, the (gradually diminishing) accumulation of foreign assets raises real wealth and, by assumption, reduces saving by domestic residents. The resulting adjustment profile of the exchange rate is depicted in Figure 2.4.

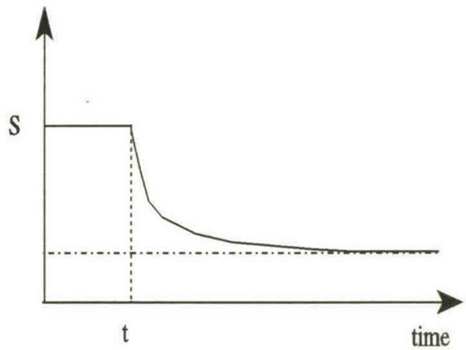

Figure 2.4 *The adjustment profile of the exchange rate after an exogenous shift in preferences for domestic goods in the Dornbusch—Fischer (1980) model*

2.3.5.3 Unsterilized intervention: current and capital account dynamics

Branson (1983) extends the standard small-country portfolio model analysed in Section 2.3.4.1 to include the interaction between cross-border flows of foreign exchange and stocks of foreign assets. The model is augmented to include an equation which describes price dynamics (equation (2.63)) and an equation for the rate of accumulation of net foreign assets (equation (2.64)). For price dynamics, Branson follows

Dornbusch (1976) in assuming slow adjustment of the price level to monetary shocks. In equation (2.63) m_R (= M/p) and m_R^* are the actual value of real balances and the equilibrium value corresponding to long-run equilibrium output, respectively. In the long run the economy is homogeneous in monetary variables with the price level changing proportionately to the money stock. This implies that if M is increased, raising m_R above m_R^*, the price level eventually rises to restore $m_R = m_R^*$. Rewriting the balance of payments identity which states that, under freely floating exchange rates, the capital account and the current account must sum to zero, gives equation (2.64). The trade balance depends positively on the real exchange rate.[20] Branson assumes that the domestic country has acquired a net foreign asset position by running a current account surplus in previous periods.[21]

In Section 2.3.4.1 it was established that an unsterilized intervention which involves an official purchase of foreign bonds in exchange for

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A small-country portfolio balance model with current account dynamics

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$$M = m\,(i,\ i^* + \dot{s}^e)\ W \qquad m_i < 0,\ \ m_{i^*} > 0 \qquad (2.56)$$

$$B = b\,(i,\ i^* + \dot{s}^e)\ W \qquad b_i > 0,\ \ b_{i^*} < 0 \qquad (2.57)$$

$$sF = f\,(i,\ i^* + \dot{s}^e)\ W \qquad f_i < 0,\ \ f_{i^*} > 0 \qquad (2.58)$$

$$W = M + B + sF \qquad (2.59)$$

$$m + b + f = 1 \qquad (2.60)$$

$$\dot{s}^e = 0 \qquad (2.61)$$

$$i^* = \bar{i}^* \qquad (2.62)$$

$$\dot{p} = \psi\,(m_R - m_R^*) \qquad (2.63)$$

$$\dot{F} = T\,\left(\frac{sp^*}{p}\right) + i^* sF \qquad (2.64)$$

m_R (= M/p) and m_R^* are actual real balances and the equilibrium value corresponding to long-run equilibrium output, respectively.

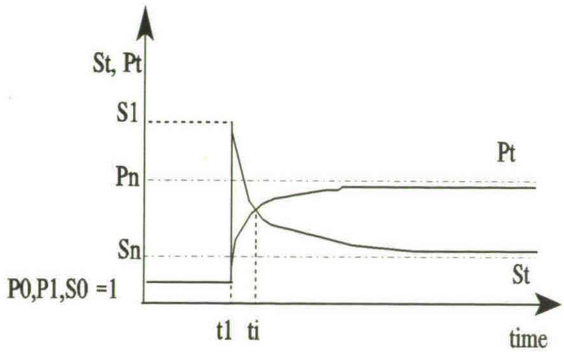

Figure 2.5 *The adjustment profile of the exchange rate and the domestic price level after an unsterilized purchase of foreign bonds by the domestic central bank at time* t_1

domestic money leads to an instantaneous reduction in the domestic interest rate and a depreciation of the domestic currency (i.e., a jump in the exchange rate from $s_0 = 1$ to s_1 in Figure 2.5). While initially domestic prices do not respond to the shock ($p_0 = p_1 = 1$ in Figure 2.5) the real exchange rate (sp^*/p, with p^* constant and normalized at one) rises along with the nominal exchange rate. The trade balance improves and a current account surplus emerges. According to equation (2.64) the domestic economy accumulates additional foreign assets. Over time, the current account surplus leads to an appreciation of the domestic currency (this is reflected by a fall in s_t beyond period t_1). Furthermore, with a gradually rising domestic price level the real exchange rate starts to appreciate even stronger. The trade balance deteriorates. At the point t_i where $s_i = p_i$ the price ratio s/p is the same as the original $s_0/p_0 = 1$. This implies that net exports have fallen to their original value. But since F, the net foreign assets position of domestic residents, has risen in the interval between t_1 and t_i, the current account balance is positive at t_i due to the higher interest earnings on foreign assets. Thus, at t_i, where $s_i = p_i$, the domestic economy is still accumulating foreign assets. To arrive in a new steady state the exchange rate has to fall. The nominal exchange rate declines and the domestic price level rises until the ratio s/p reaches the value where $T\ (sp^*/p) = i^*\ F$ once again. At that point the current account is in equilibrium and the adjustment process is completed.

2.3.5.4 Sterilized intervention: current and capital account dynamics

By definition, a sterilized intervention has no effect on the domestic money supply. As a result, the extended portfolio model featuring the sticky-price equation (2.63) analysed in the previous section does not provide an appropriate framework to investigate the effects of a pure intervention. Instead, the framework provided by Hallwood and MacDonald (1986, Chapter 7) will be used to track the long-term effects of sterilized intervention when otherwise identical assets denominated in different currencies are imperfect substitutes. Hallwood and MacDonald extend the standard small-country portfolio model analysed in Section 2.3.4.1 to comprise a traded goods sector and a non-traded goods sector in the domestic economy. Traded goods are exposed to international competition. Therefore, they are priced according to the law of one price (equation (2.63)').

$$P^T = sP^{T*} \tag{2.63'}$$

$$Y^D = Y + i^* sF \tag{2.65}$$

$$C = Y^D - \Omega\,(w^* - w) \tag{2.66}$$

$$\dot{F} = T\left(\frac{sp^*}{p}\right) + i^* sF = \Omega\,(w^* - w) \tag{2.64'}$$

Equation (2.66) states that domestic spending depends positively on disposable income which is made up of domestic income plus net interest earnings on the stock of foreign assets (equation (2.65)) and negatively on the discrepancy between constant desired real wealth w^* and actual real wealth w. From an accounting identity it follows that the accumulation of foreign assets over time is equal to a constant fraction Ω of the discrepancy between desired and actual real wealth. As before, the trade balance and hence the accumulation of foreign assets is assumed to depend positively on the real exchange rate.

In Section 2.3.4.1 it was established that a pure intervention involving a swap of domestic currency-denominated bonds for foreign currency-denominated bonds leads to an instantaneous rise in both the domestic interest rate and the exchange rate. From the law of one price, the rise in the exchange rate implies a rise in the domestic currency price of traded goods. This has two effects. Firstly, the higher price of traded goods induces domestic producers to shift resources to the traded goods sector. Domestic consumers, on the other hand, will buy relatively more non-traded goods. The world demand for traded goods is infinitely elastic. Therefore, the resulting excess supply of traded goods in the domestic economy will be exported thus improving the trade balance of the domestic economy. Secondly, the higher price of traded goods raises the overall domestic price level and drives real wealth below the desired level w^*.[22] By assumption, domestic residents lower consumption in order to save more and restore real wealth. The improved trade balance facilitates a deficit on the capital account. This implies that domestic residents indeed acquire foreign assets and hence restore real wealth to the desired level. The current account surplus puts upward pressure on the value of domestic currency. Therefore, in the course of the adjustment to the new steady state the domestic currency appreciates (i.e., s falls) and the rate of accumulation of net foreign assets gradually diminishes to zero. The new long-run equilibrium consequent upon the initial swap of domestic for foreign bonds must be one in which the nominal exchange rate has risen (see the adjustment profile in Figure 2.6). Due to the accumulation of foreign assets in the adjustment period, interest receipts on the foreign assets must *ceteris paribus* be greater in the new equilibrium. Then, equilibrium on the current account allows a higher trade deficit which corresponds to an *appreciation* of the real exchange rate.[23]

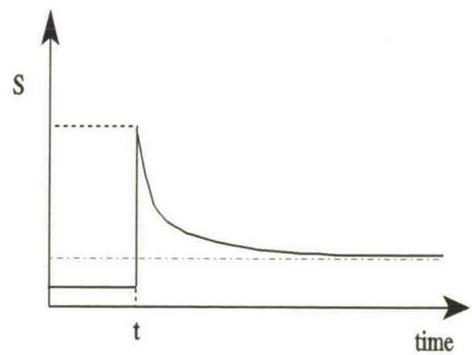

Figure 2.6 *The adjustment profile of the exchange rate after a sterilized purchase of foreign bonds at time* t

2.3.5.5 A comprehensive portfolio balance model by Pilbeam (1991)

Pilbeam (1991, pp. 93—103) presents a comprehensive dynamic portfolio balance model. Pilbeam postulates perfect foresight on the part of foreign exchange market participants. He compares both the impact effects and the long-run effects of open market operations and unsterilized and sterilized interventions. Pilbeam generally reproduces the results discussed in the two previous sections. Both monetary and pure intervention operations trigger an initial jump depreciation of the exchange rate followed by a gradual appreciation. However, the author concludes that a sterilized foreign exchange operation has a relatively weaker effect on the nominal exchange rate than an unsterilized foreign exchange operation.

A long-run steady-state equilibrium condition in the zero-growth model by Pilbeam is that the current account balance is zero. During the transition to the new long-run equilibrium after the initial intervention operation the domestic economy accumulates net foreign assets. The accompanying increase in net interest receipts from abroad improve the service component of the current account. To ensure a current account balance of zero in the long run it is necessary for the real exchange rate to appreciate.

In Section 1.3.2 it was concluded that an expansionary monetary policy and an unsterilized purchase of foreign currency have similar effects. Pilbeam (1991, p. 103) shows that in his portfolio balance model the initial jump in the exchange rate is greater following an unsterilized intervention; an expansionary monetary policy does not lead to an initial fall in private agents' holdings of foreign assets, but it does lead to a fall in the domestic interest rate. In the portfolio balance model this induces an excess demand for foreign assets, which coincides with the impact effect of an unsterilized purchase of foreign bonds by the domestic central bank. Clearly, this confirms that the preliminary conclusion of Section 1.3.2 about the identical effects of monetary policy and unsterilized exchange rate policy only applies when domestic and foreign bonds are perfect substitutes.

Pilbeam is clear about the working of a sterilized intervention carried out to support the value of the foreign currency:

> The authorities ... increase the amount of domestic bonds in private portfolios via an SFXO [a sterilized foreign exchange operation] above the minimum variance portfolio share, thereby increasing the risks in private asset-holders' portfolios. Accordingly, asset-holders require a risk premium in the way of a higher domestic interest rate and expected appreciation of the domestic currency to compensate. Hence an SFXO works by breaking up the uncovered interest rate parity condition via manipulation of the risk premium. When there is no risk premium to manipulate an SFXO cannot work. (Pilbeam 1991, pp. 108—9)

The author notes that a central bank may be unwilling to exploit the possibility of using sterilized interventions. They may require substantial changes in foreign exchange reserves to exert significant exchange rate effects. The empirical investigations surveyed in Chapter 3 will give some indication of the magnitude of sterilized intervention required to have exchange rate effects.

2.4 ALTERNATIVE APPROACHES TO THE STUDY OF INTERVENTION

2.4.1 Introduction

The theoretical investigations discussed in the previous sections all assumed that some structural model of exchange rate determination provides a valid framework for the analysis of the effectiveness of foreign exchange market intervention. After surveying the empirical evidence on exchange rate models, MacDonald and Taylor (1992) conclude that

> the asset approach models have performed well for some time periods, such as the interwar period, and, to some extent, for the first part of the recent floating experience (that is, 1973—1978); but they have provided largely inadequate explanations for the behavior of the major exchange rates during the latter part of the float. (op. cit., p. 24)

Discontent with the performance of traditional structural exchange rate models in explaining the actual behaviour of exchange rates has led many economists to adopt new research strategies in exploring the field of exchange rate economics.

2.4.2 De Grauwe's (1989) near-rationality model

Two basic assumptions underlie all asset-market models of the exchange rate. Firstly, foreign exchange market participants calculate the long-run equilibrium value of an exchange rate (S^*) based on, *inter alia*, expectations about the future value of the 'fundamentals'. Secondly, market participants take positions in foreign currencies to exploit the difference between the spot rate which prevails at a certain moment and the calculated long-run equilibrium value.

De Grauwe (1989, pp. 160—63) argues that there are no models which provide a reliable guide for forecasting the future exchange rate. De Grauwe emphasizes the crucial role of uncertainty among foreign exchange market participants regarding the future course of currency movements. Within a mean-variance framework, in which it is assumed that currency traders trade off the expected gain from operating in the foreign exchange market against the risk involved, he shows that it is not necessarily profitable to use all available fundamental economic information. For instance, an individual exchange market participant may observe a gap between the actual level of the exchange rate and the perceived fundamental equilibrium value. In a highly uncertain economic environment, the expected gain from taking a forward position aimed at exploiting this gap may not outweigh the risk involved.

Due to the risk involved in fundamental analysis it can be rational for exchange market participants to implement technical analysis. De Grauwe presents a rule for the formation of exchange rate expectations that consists of a backward-looking and a forward-looking component, the first term and the second term on the right-hand side of (2.67), respectively:

$$E_t \, \Delta S_{t+1} = k \, (\sum_{i=0}^{n} c_i \, \Delta S_{t-i}) + (1-k) \, (S^* - S_t) \tag{2.67}$$

The parameter k which represents the weight given to each of the expectation rules is assumed to be endogenous. Exchange market participants choose to let the backward-looking component dominate their expectations formation (high value of k) when the actual exchange rate is not too far away from the equilibrium rate they have in mind (S^*). This implies that they resort to technical analysis. A higher weight is assigned to the forward-looking component (lower value of k) only when it is obvious that the actual exchange rate is at an unsustainable level. Foreign exchange trading based on fundamental analysis becomes less risky leading to a larger expected utility in a mean-variance framework.

Chartism is a specific form of technical analysis. It involves forecasting exchange rate movements based on perceived patterns or regularities in past currency movements (some authors call it feedback-trading, see Menkhoff (1992) for a survey). The popular financial press has already adopted the concomitant vocabulary of 'resistance levels', 'support lines' and 'technical corrections'. In an attempt to ascertain the extent and manner by which chartism is used, Allen and Taylor (1989) conducted a questionnaire survey among more than 200 chief foreign exchange dealers in the London market. They found, *inter alia*, that

> at the shortest horizons, intraday to one week, approximately 90% of respondents use some chartist input in forming their exchange rate expectations, with 60% judging charts to be at least as important as fundamentals. At longer forecast horizons, of one to three months or six months to one year, the weight given to fundamentals increases. (Allen and Taylor 1989, p. 50)

Additional evidence for non-fundamental trading strategies on the part of private exchange market participants is provided by De Grauwe and Decupere (1992). They cannot reject the hypothesis that psychological barriers exist in the Japanese yen-US dollar market. For the Deutsche Mark-US dollar market the results are mixed.

By assuming that exchange market participants revert to backward-looking technical analysis instead of forward-looking fundamental analysis in cases of extreme uncertainty, De Grauwe's near-rationality model can account for some stylized facts of (real) exchange rates which are left unexplained by perfect foresight rational expectations models, i.e. real exchange rates wandering away from levels implied by fundamentals for long periods of time before being pushed back towards equilibrium and the relative sluggishness of exchange rate movements as compared to stock and commodity price movements.

While the current global exchange rate system offers no credible anchor for exchange rate expectations, De Grauwe (1989) sees no role for *ad hoc* (un)sterilized intervention to remedy persistent deviations of exchange rates from their perceived equilibrium values. In his view, even changes in fundamentals brought about by monetary or fiscal policy will not help. Due to the extreme uncertainty as to the true model, market participants do not know how to interpret these changes. De Grauwe argues that only a credible exchange rate commitment by the monetary authorities, i.e. a commitment embodying a clear and stabilizing guide for exchange market participants' expectations, can facilitate an efficient functioning of the foreign exchange market comparable to stock and commodity markets. This would require systematic unsterilized interventions rather than *ad hoc* (un)sterilized central bank operations in foreign exchange with which the analysis in the previous sections was concerned.

In sum, De Grauwe's analysis, which takes account of non-fundamentalist behaviour or, to be more precise, chartist behaviour by (some) foreign exchange market participants, does not reveal a distinct channel through which foreign exchange intervention can affect the course of currency movements.

2.4.3 The chartist channel and noise trading signalling channel of intervention

Fukao (1985) argues that the scope for intervention changes quite dramatically when one is willing to drop the assumption that the foreign exchange market is efficient in the sense that market participants use some structural model as a yardstick when taking positions on the foreign exchange market. Fukao presents the following table which is both simple and insightful (see Table 2.2).

Fukao (1985) does not clarify how the inefficiency of the foreign exchange market opens up a distinct channel through which foreign exchange intervention can affect the exchange rate. Hung (1991a,b) contends that the presence of non-fundamentalist market participants whose trading behaviour is more or less predictable constitutes a channel through which sterilized intervention can be effective. Hung conducts her analysis in the framework of a partial equilibrium flow-market approach

Table 2.2 The state of the foreign exchange market and the effectiveness of central bank intervention (Source: Fukao 1985, p. 26)

	Substitutability of bonds denominated in different currencies	
	Perfect	Imperfect
Efficient market	Intervention is ineffective	Intervention is effective
Inefficient market	Intervention is effective	Intervention is effective

to exchange rate determination. If a large enough group of noise traders use the same forecasting technique or share the same belief with respect to the future course of the exchange rate, expectations may turn out to be self-fulfilling. The central bank may want to counter the resulting currency movements. Hung argues that the noise trading behaviour displayed by market participants in itself offers an opportunity for the central bank to do this successfully.

Hung's approach is slightly different from that of De Grauwe (1989). The noise trading behaviour by exchange market participants is not derived formally. Earlier work on noise trading is just put to the right use. Like De Grauwe, Hung arrives at the important insight that fundamentalists can at times turn into noise traders due to the extreme uncertainty regarding the future path of the exchange rate. She distinguishes two categories of non-fundamentalist or noise traders. *Chartists* 'rely on analysis of past price patterns to predict the future direction of exchange rate movements' (Hung 1991a, p. 12). Market participants who base trading on their prediction of the market's reaction to news and rumours are called *non-chartist noise traders*.

A necessary but of course not sufficient condition for intervention to be effective is that the central bank can imagine itself in the position of the two groups of noise traders distinguished. Current intervention volumes are insufficient to counter a strong underlying trend in the exchange rate. Therefore, the decision when and how to intervene has to be made conditional on information about the general market sentiment and the (strength of the) buy or sell signals adherents of technical analysis derive from their charts. Hung (1991a, p. 20) presents an ideal picture in which chartists 'help amplify and prolong the effect of intervention' which may be transitory by itself. The central bank should select a time period during which the market is sufficiently thin.

Concealed intervention carried out through brokers may cause just enough upward or downward pressure on the currency under consideration which, if incorporated in the chartists' trendline analysis induces them to reinforce the movement of the exchange rate in the direction favoured by the central bank. This is what Hung calls the *chartist channel of intervention*. When the interventions indeed remain anonymous, the central bank has nothing to lose in terms of reputation.[24] On the other hand, Hung (1991b) admits that

> chart analysis has a large subjective element, and there are probably as many methods of combining and interpreting the various techniques as there are chartists themselves. (op. cit., p. 7)

A second channel is the *noise trading signalling channel*. For this channel, the opportunity to influence the course of the exchange rate does not lie in the thinness of the market or the fact that traders only stare at their charts. For the noise trading signalling channel to be effective, noise traders must be 'already looking for any sign or excuse to reverse their position' (Hung 1991b, p. 12). Highly visible interventions, conducted via the interbank market could give just such a signal.

2.5 CONCLUSIONS

The aim of this chapter was to provide a comprehensive picture of theories on the scope for foreign exchange market intervention and to find out whether and how intervention is able to influence the course of the exchange rate.

In Section 1.3 it was established that the exact implications of an operation in foreign currency by the domestic central bank depend on who is the counterpart in the transaction, the non-bank private sector or the domestic commercial bank. However, in theoretical models without a fractional reserve private banking system this distinction is not relevant. In the latter case, the initial official operation in foreign exchange can only be carried out with 'the private sector' as the counterpart in the transaction.

Some well-established models of exchange rate determination were examined whereby focus was on the channels of influence of unsterilized and sterilized intervention in these models. In the case of perfect substitutability between bonds denominated in different currencies, in the end, there is no difference between domestic monetary policy on the one hand and unsterilized intervention on the other hand. Therefore, the conclusions regarding the effectiveness of unsterilized interventions, working through the *monetary channel*, are much the same as those that would arise if one were to investigate the effect(iveness) of monetary policy on the exchange rate. Overall, the effectiveness of monetary intervention in the various models studied is undisputed. Even elementary PPP predicts that an unsterilized intervention will in the long run, *ceteris paribus,* influence the level of the exchange rate in a one-to-one relationship with a purchase of foreign currency by the domestic central bank leading to a rise in the value of foreign exchange in terms of the domestic currency. In the theoretical models investigated in Sections 2.2 and 2.3, sterilized intervention can only be effective in cases where risk-averse investors believe assets denominated in different currencies to have different risk characteristics. In that case, a swap of domestic bonds for foreign bonds in the portfolio of the private sector brought about by a sterilized purchase of foreign currency by the domestic central bank can lead to an appreciation of foreign currency. When domestic bonds are considered to be the relatively risky asset investors require an inducement to switch their foreign bonds for domestic bonds. Consequently, the expected rate of return on domestic bonds has to rise relative to that on foreign bonds to enhance the attractiveness of domestic bonds. An expected appreciation of the domestic currency can do the job: with the (longer-term) expected exchange rate assumed constant, the value of domestic currency has to decline.

In portfolio balance models sterilized interventions have an impact effect on the exchange rate. However, the initial change in the exchange rate triggers off current account and capital account dynamics which, in turn, do not leave the exchange rate unaffected. In fact, in Sections 2.3.5.4 and 2.3.5.5 it was established that over time the initial (nominal) exchange rate change is reversed at least partly. Moreover, in the new steady state the real exchange rate turns out to have undergone a real appreciation when, on impact, the sterilized intervention accomplished a nominal depreciation. This does not exactly seem to be what the monetary authorities were looking for at the time they decided to intervene. The practical relevence of the *portfolio balance channel of intervention* is an empirical issue which will be addressed in Chapter 3 of this book.

Attention was also paid to the popular insight that sterilized intervention can alter the current exchange rate through what is called the *expectations or signalling channel of intervention* by providing private exchange market participants with new information or a signal about the future course of monetary policy. It was argued that for the signalling hypothesis to be valid central banks have to back up interventions with subsequent changes in monetary policy. In other words, current sterilized interventions predetermine the path of future money growth and hence interfere with monetary policy. The neutralization of the initial intervention's money-market effect is limited to the short run. This no longer meets the definition of sterilized intervention presented in Chapter 1.

From Section 2.4 it appears that the scope for intervention changes quite dramatically when one is willing to drop the assumption that the foreign exchange market is efficient in the sense that market participants use some structural model as a yardstick when taking positions on the foreign exchange market. However, the literature on how the inefficiency of the foreign exchange market opens up distinct channels through which intervention can affect the exchange rate is still in its infancy.

NOTES

1. This chapter is based on Almekinders (1994c).
2. Edison, Gagnon and Melick (1994) argue that the failure of most empirical studies to find evidence for PPP in the post-Bretton Woods era can be attributed largely to the low power of the tests employed. Using a new testing procedure they find moderate evidence for PPP in post-Bretton Woods data.
3. Under static expectations the exchange rate which is expected to prevail in the next period equals the current exchange rate. Hence, $\dot{s}^e = 0$ and the uncovered interest parity condition reduces to $i = i^*$.
4. This representation of the Mundell—Fleming model is mainly due to MacDonald (1988, pp. 42—7).
5. This is due to the implicit assumption that changes in the exchange rate do not lead to alterations in the domestic price level.
6. These are two assumptions which underlie the flexible-price monetary model which is discussed in Section 2.3.2.
7. Intervention aimed at reducing the difference between the current exchange rate s_t and the target rate s^T reduces the level of uncertainty about the exchange rate provided that the target chosen by the monetary authorities is equal to the PPP-implied long-run equilibrium value which rational private speculators regard as the true long-run equilibrium exchange rate.
8. For a lucid exposition on the derivation of this solution for the exchange rate in the monetary model with rational expectations, see Visser (1989, pp. 18—22).
9. Klein and Rosengren (1991) use newspaper reports on dollar intervention by the United States and Germany. They found no evidence for interventions systematically preceding changes in monetary policy. Furthermore, periods of active intervention were not followed by monetary policy changes. Kaminsky and Lewis (1992) strongly reject the hypothesis that interventions convey no signal. However, they also find that in some episodes, intervention signalled changes in monetary policy in the opposite direction of the conventional signalling story.
10. A theoretical explanation for this phenomenon can be found in Okun (1981). Okun distinguishes customer markets from auction markets. The market for domestic goods is a customer market. On such a market the price is the result of an ongoing relationship between buyer and seller. Therefore price changes on customer markets are costly. Money and bonds are traded in auction markets on which buyers and sellers are more or less anonymous. Moreover, traders on auction markets are used to prices changing in real time.
11. Gray and Turnovsky (1979) derive an expression for the value of Θ (Θ^*) for which the

Dornbusch model has the saddlepoint-property. Furthermore, they show that within this model equation (2.20) with $\Theta = \Theta^*$ is the only *ad hoc* expectations hypothesis consistent with perfect foresight.

12. Djajic and Bazzoni show that for certain parameter values the jump in the money supply is slightly *larger* in the case of 'leaning against the wind' intervention than in the case of fixed exchange rates. In my view this is a technical artefact of the model which defies economic explanation. Furthermore, it is not clear at all whether these parameter values imply a realistic degree of 'leaning against the wind' intervention.
13. Stock-flow interaction in portfolio models of the exchange rate is discussed in Section 2.3.5.
14. See note 14, Chapter 1.
15. In the case of perfect substitutability the latter exchange rate change does not occur. Furthermore, the demand for bonds denominated in either currency are perfectly elastic. Hence, after the swap of domestic for foreign bonds only an incipient rise (decline) of the domestic (foreign) interest rate is sufficient to restore equilibrium in all three financial markets in the model.
16. Note that a subscript t is attached to this expression for the target exchange rate of private investors. This indicates that the current analysis is concerned with a sequence of negative shocks to exchange rate expectations rather than a one-time expected appreciation of the domestic currency. The updating of the target rate by investors in this case implies that $E_t\, s_{t+1} > E_{t+1}\, s_{t+2} > E_{t+2}\, s_{t+3}$, etc.
17. Intervention-induced increase in the money supply: $\Delta\, m_t > 0$. From equation (2.47) with $p_m > 0$ it follows that $\Delta\, p_t > 0$.
18. Official purchase of foreign bonds: $\Delta\, f_t < 0$. From equation (2.47) with $p_f < 0$ it follows that $\Delta\, p_t > 0$.
19. Revision of expectations: $\Delta\, (E_t s_{t+1} - s_t) < 0$. From (2.47) with $p_s > 0$ it follows that $\Delta\, p_t < 0$.
20. Obviously, the assumption of continuous PPP would imply that sp^*/p is constant. Here, this assumption is not imposed. Rather, p (and F) are state variables which adjust slowly while the exchange rate s can jump in the short run.
21. In a steady state with both the capital account and the current account in equilibrium, interest earnings on the foreign asset position allow the domestic economy to run a trade deficit.
22. This hinges on the implicit assumption that the fall in real wealth due to the rising overall price level in the domestic economy is larger than the rise in real wealth brought about by the rise in the exchange rate and the concomitant rise in the domestic currency value of foreign bonds (see equation (2.59)).
23. The real exchange rate was previously defined as $s_R = sp^*/p$. Hallwood and MacDonald (1986) define the real exchange rate as the relative price of traded to non-traded goods: $s_R = p^T/p^N$. This definition is often used in the context of two-sector models.
24. The latter condition may account for the fact that detailed intervention data are not made publicly available by central banks.

3. Empirical Investigations into the Objectives and Effectiveness of Intervention: A Survey

3.1 INTRODUCTION[1]

The previous chapter surveyed the theoretical literature on exchange market intervention. An explicit assumption in most of this literature is that central banks try to minimize deviations of the actual exchange rate from a target level implied by 'fundamentals' (see, e.g., Neumann 1984, and Natividad and Stone 1990) and/or that central banks try to dampen the short-term volatility of exchange rates. This chapter surveys empirical studies which have been carried out to assess which objectives the central banks of the main industrial countries pursued with their interventions in the foreign exchange market.

The central question in the previous chapter was whether and how, in theory, non-sterilized and sterilized interventions are able to influence the course of the exchange rate. This chapter reviews empirical studies which address the question of whether, in practice, (sterilized) intervention has been capable of exerting a significant influence on the exchange rate.

As before, an exchange market intervention is defined as a sale or a purchase of foreign currencies undertaken by the central bank to change the exchange rate of their own currency *vis-à-vis* one or more foreign currencies. The distinction that is sometimes made between 'active intervention' and 'passive intervention' does not seem very helpful as far as empirical research is concerned. By definition, passive intervention is distinguished from active intervention in that it is carried out outside instead of inside the exchange market. It is of course at the discretion of a central bank to carry out a sale of foreign exchange inside or outside the market depending on the strength of its own currency.

By far the larger part of exchange market intervention is carried out in the spot market. While 'analytically there is no distinction between the effects of forward market and sterilized spot market transactions on the spot exchange rate' (Smith and Madigan 1988, p. 189) the reason for this seems to be that an intervention operation derives a great deal of its effect from the announcement of the operation itself. Highly visible spot market operations confirm the announcement.

In general, the empirical investigation of objectives and effectiveness of exchange market intervention is hampered by a lack of sufficiently detailed data. It is well known that, for example, the German and Swiss central banks swap foreign exchange with the commercial banks. Changes in official reserves include these swaps, implying that they do not accurately reflect intervention. Taylor (1982) puts forward the problem of concealed intervention not showing up in the official international reserve figures. For instance, one can think of industries under public ownership intervening in the foreign exchange market acting as an agent for the central bank. However, this is probably a phenomenon of the 1970s.[2]

This chapter is organized into three remaining sections. Section 3.2 surveys the results of sixteen empirical studies into the objectives of central bank intervention. The discussion of the individual studies is preceded by a concise exposition of some theoretical and technical insights. Analogously, Section 3.3 discusses eleven empirical investigations into the effectiveness of intervention. Section 3.4 summarizes the main conclusions.

3.2 OBJECTIVES OF INTERVENTION

In the theoretical literature two divisions of objectives can be found. First, in the Jurgensen report (1983) the objectives are classified according to whether the central bank pursues them on a long-term or a short-term basis. Second, German economists like Lehment (1980) and Sommer (1983) use the kind of objective which underlies the intervention as the division criterion. The latter division criterion distinguishes four categories of interventions. 'Anpassungs'-interventions (in English corresponding with 'smoothing'-interventions) *grosso modo* refer to interventions undertaken on account of a 'leaning against the wind' policy. The central bank tries to resist large short-term exchange rate movements without affecting the underlying trend. Interventions carried out to alter the trend in the development of the exchange rate for economic or political reasons are called 'Erhaltungs'-interventions ('trend breaking'-interventions), whereas 'Gestaltungs'-interventions ('direction indicating'-interventions) apply to the situation where the exchange rate is moving out of control. Finally, the category 'other interventions' covers sales and purchases of foreign currencies owing to the management of the volume and composition of the foreign exchange market reserves of the central bank.

It appears that the detailed division of objectives in the Jurgensen report is not in accordance with the practical implementation of intervention policy. To formulate medium-term and long-term objectives is one thing. To carry out exchange market interventions aimed at realizing those objectives while one is not even able to control the exchange rate movements in the short run is something totally different.

Most empirical studies postulate a central bank intervention reaction function rather *ad hoc*. Some derive it formally, however. For instance, this is done by combining a policy loss function with a set of equations describing the determination of the exchange rate of foreign currency in terms of domestic currency (S_t). The policy loss function — which is postulated *ad hoc*! — reflects the hypothesis that the central bank in the domestic country wishes to limit deviations of the actual exchange rate from a target level for the exchange rate (S_t^T):

$$L_t^{CB} = (\log S_t - \log S_t^T)^2 = (s_t - s_t^T)^2 \tag{3.1}$$

with $s_t = \log S_t$ and $s_t^T = \log S_t^T$. To capture intervention carried out on account of a 'leaning against the wind' policy, the target level for the exchange rate can be thought of as representing past levels of the exchange rate. This follows immediately from the definition of smoothing exchange rate fluctuations: whether or not the exchange rate was considered to be at a desirable level in the previous period(s), deviations from this target level will be countered.

The dramatic increase of the exchange market turnovers has caused proper timing of the interventions and the use of the correct intervention technique to become of growing importance in the exchange rate policy of the central banks. However, it is not possible to estimate a reaction function which reflects that the central bank only intervenes 'when such action can be expected to dampen adverse exchange rate movements' (Dudler 1988, p. 69) and that 'monetary policy-makers have hesitated to react as long as there seemed to be a chance that external disturbances or erratic exchange rate movements could reverse themselves within a reasonable time' (Dudler 1988, p. 76). The estimated reaction functions only account for the volume and direction of intervention transactions. This reduces the explanatory power of the estimated relations.

All investigations under review are concerned with spot market interventions only. In the estimated reaction functions the volume of intervention in consecutive periods (INV_t) is the dependent variable that has to be explained by the independent variables of which the percentage change in the exchange rate ($s_t - s_{t-1}$) and the difference between the actual level of the exchange rate and a target level for the exchange rate ($S_t - S_t^T$) are the most important ones. However, account has to be taken of the fact that exchange rates and intervention volumes are determined simultaneously and, hence, that exchange rate changes may not be an exogenous explanatory variable in the intervention reaction function. For example, when the estimation is carried out using weekly data, the exchange rate change in one week ('independent variable') will be simultaneously determined by the interventions undertaken in the same week (dependent variable). Consequently, the estimation results are subject to simultaneity bias. In an attempt to reduce the simultaneity bias, some studies use the two-stage least squares (2SLS) or the instrumental variables (IV) estimation technique. In any case, the estimation results have to be interpreted carefully. It should be stressed that the empirical tests of the objectives of intervention policy are rather indirect in the sense that estimates of the reaction functions assume the underlying model to be the true model. Therefore, estimation results may not only be an indication of objectives of intervention policy, but also of the strength of the underlying model.

The remainder of this section reviews a number of empirical investigations into the objectives of exchange market intervention. Their main characteristics are summarized in Table 3.1.

Artus (1976) studies the intervention policy of the Bundesbank (DBB) over the period March 1973—July 1975. He finds evidence of a 'leaning against the wind' policy. A rise (fall) by one percentage point in the value of the DM in terms of the US dollar ($\dot{S}_t$) during one month on average gave rise to the buying (selling) of 0.359 billion DM worth of foreign exchange over the same one-month period. Furthermore, the German central bank on average bought (sold) 463 million DM of foreign exchange 'for each US $ 0.01 of discrepancy between the current value of the deutsche mark in US cents and its target value' (Artus, 1976, p. 329). The target level for the exchange rate is based on relative prices in the Federal Republic of Germany (P_G) and the United States (P_{US}). Estimation results for the structural equations are shown below with t-values in parentheses.

$$INV_t = \underset{(4.98)}{0.463} \left(S_t - S_t^T \right) + \underset{(6.30)}{0.359} \, \dot{S}_t \tag{3.2a}$$

$$S_t^T = 40.2 - 54.8 \left(P_G / P_{US} - 1 \right) \tag{3.2b}$$

The findings of Quirk (1977) with respect to the intervention behaviour by the Bank of Japan (BoJ) are similar to those of Artus' study of German intervention policy. However, Quirk is not able to relate the interventions to the deviation from a target level for the yen exchange rate. Instead, the total volume of spot transactions on the Tokyo foreign exchange market and the lagged endogenous variable are significant independent variables in explaining the intervention response. A one per cent exchange rate change of the yen *vis-à-vis* the US dollar was accompanied on average by intervention amounting to \$156 million in the month the exchange rate change occurred and \$78 million thereafter. Quirk ascertained that the interpretation of the OLS estimates was not hampered by a simultaneity bias after comparing the results with those of 2SLS estimates.

Branson, Halttunen and Masson (1977, 1979) try to apply the asset-market model empirically to the US dollar—DM exchange rate. To obtain consistent results, a reaction function for intervention is estimated simultaneously with an equation determining the level of the exchange rate. Branson, Halttunen and Masson relate Germany's reserve position in period t to the reserve position in period t—1 and the change in the index of the US dollar/DM exchange rate that occurred between the end of period t—1 and the end of period t. A rise (fall) of the \$/DM exchange rate index by one point caused the Bundesbank to 'lean against the wind' by purchasing (selling) \$83 million when estimated over the period 1971(8)—1976(12), and \$180 million when estimated over the period 1971(8)—1978(3).

Dornbusch (1980) assumes that central banks calculate the unanticipated depreciation of the US dollar ($\dot{S}_t^{UA}$), defined as the difference between the actual depreciation of the US dollar *vis-à-vis* their own currencies ($\dot{S}_t$) and the depreciation that investors had already anticipated upon by demanding a risk premium on assets denominated in US dollars:

$$\dot{S}_t^{UA} = \dot{S}_t - (i_t^{\$} - i_t^{*}) \tag{3.3}$$

The intervention behaviour of the major industrialized countries taken as a whole (INV_t) is explained rather poorly by the unanticipated depreciation of the effective exchange rate of the US dollar, indicating perhaps that one or more important explanatory variables have been left out of the estimated reaction function. The main result of the estimations looks as follows:

$$\begin{aligned} INV_t = \underset{(104.8)}{1.00} + \underset{(3.22)}{0.003}\ \dot{S}_t^{UA} + \underset{(1.68)}{0.001}\ \dot{S}_{t-1}^{UA} \end{aligned} \tag{3.4}$$

$$R^2 = 0.38 \quad DW = 1.81 \qquad SEE = 0.05$$

t-values are in parentheses, R^2 is the squared multiple correlation coefficient, DW is the Durbin—Watson statistic for first-order autocorrelation and SEE is the standard error of the estimate. For example, an unanticipated one percentage point depreciation of the nominal effective exchange rate of the US dollar during a quarter led to a cumulative intervention of 0.4 per cent of foreign net claims on the United States.

Table 3.1 The objectives of foreign exchange market intervention. Some characteristics of the studies reviewed

	Period	Data	Estimation technique	Definition of intervention	Exchange rate	Intervening central bank
Artus (1976)	1973(3)—1975(7)	monthly	2SLS	change in the net foreign assets of the Bundesbank (in billions of DM) (p. 31)	spot rate of the Deutsche Mark in terms of US dollars	DBB
Quirk (1977)	1973(3)—1976(10)	monthly	OLS & 2SLS	changes in the Foreign Exchange Fund account (in millions of dollars) (p. 650)	spot rate of the yen in terms of US dollars	BoJ
Branson et al. (1977) Branson et al. (1979)	1971(8)—1976(12)/1978(3)	monthly	2SLS	International reserves of Germany (in US dollars) minus cumulated SDR allocations (p. 323)	spot rate of the Deutsche Mark in terms of US dollars (index: 1970 = 100)	DBB
Dornbusch (1980)	1973(III)—1979(IV)	quarterly	OLS	changes in reserves (except for interest earnings) as a fraction of lagged reserves (p. 713)	— effective spot rate of the US dollar — spot rate of the DM and the yen in terms of US dollars	DBB, BoJ, BoC,BdF and BoE
Lehment (1980)	1973(4)—1978(12)	monthly	OLS	average monthly changes of the adjusted net reserve position of the Bundesbank (p. 220)	spot rate of the DM in terms of US dollars	DBB

Longworth (1980)	1950(10)—1962(5) 1970(6)—1977(12)	monthly	OLS	change in foreign exchange reserves + change in net undelivered contracts in US dollars — revaluation items and SDR allocations (in US dollars) (p. 285)	month-end change in the number of Canadian cents per US dollar	Bank of Canada
Argy (1982)	1972(3)—1979(12)	monthly	OLS	changes in the net external position of the DBB due to intervention (p. 37), changes in foreign reserves of the BoJ (p. 50), changes in the balance for official financing of the BoE (p. 59) (in mill. of US dollars)	effective exchange rate of the DM, the yen and the pound *vis-à-vis* the currencies of 15 other major countries (p. 35)	DBB BoJ BoE
König and Gaab (1982)	1973(4)—1982(1)	monthly	OLS	changes in the stock of foreign exchange reserves in billions of DM (p. 190)	change in the spot rate of the US dollar in terms of DM	DBB
Neumann (1984)	1974(3)—1981(12)	monthly	nl OLS	direct transactions of the Bundesbank in the US dollar—DM market (p. 237)	(log of the) spot rate of the DM in US dollars	DBB
Bischofberger (1986)	1973(7)—1980(12)	monthly	OLS	change in total reserves minus gold (Fra., UK, It., Jap. and Can.) or change in foreign exchange reserves (Ger., Swi. and US) deflated by volume of trade (p. 45)	— effective spot rate of currencies of G-7 countries plus Switzerland — spot rate of the Swiss franc and the G-7 currencies (except US dollars) in terms of US dollars	central banks of the G-7 plus Switzerland

(Table 3.1 continued)

	Period	Data	Estimation technique	Definition of intervention	Exchange rate	Intervening bank
Kearney & MacDonald (1986)	1973(II)—1982(IV)	quarterly	OLS & IV	changes in foreign exchange reserves (p. 363)	spot exchange rate of the US dollar in terms of sterling (p. 350)	Bank of England
Gärtner (1987)	1974(1)—1984(6)	monthly	OLS & IV	percentage change of foreign exchange reserves (in mill. of US dollars) (p. 452)	(log of the) real exchange rate of the Swiss franc in US dollars	Swiss National Bank
Gaiotti et al. (1989)	1973(4)—1987(12)	monthly	OLS & IV	Germany: interventions in the DM/dollar market which affect the net external position of the Bundesbank. Japan: total net official sales of the national currency (p. 31)	spot rate of the DM and the yen in terms of US dollars	DBB & BOJ
Honegger (1989)	1974(1)—1985(12)	monthly	OLS & VAR	changes in foreign exchange reserves in billions of US dollars (p. 160)	spot rate of the US dollar in terms of the currencies of each of the five countries	DBB,Boc SNN BoE BoJ
Eijffinger & Gruijters (1991)	1985(2)—1988(9)	daily	OLS	'active' intervention inside the US dollar/DM market (p. 2)	spot rate of the US dollar in terms of DM	DBB & FED
Dominguez & Frankel (1993a)	1982(11)—1988(12)	daily	IV	consolidated daily official foreign exchange transactions in the $/DM market at current market values excluding passive interventions (p. 72)	spot rate of the DM in terms of the US dollar	DBB & FED

Lehment (1980) distinguishes two estimation periods. For the first period, April 1971—December 1975, the results show a significant proportional relationship between changes in the exchange rate of the DM in terms of US dollars and changes in the reserve position of the Bundesbank. However, for the period January 1976—December 1978, there are no signs of a 'leaning against the wind' policy. Lehment supposes that this is caused by the fact that the Bundesbank aimed its interventions at keeping the $/DM exchange rate within a certain target zone. However, this presumption is not tested.

Longworth (1980) is the first study to go beyond the usual verification of the 'leaning against the wind' behaviour of the Bank of Canada (BoC). Longworth investigates whether the BoC has a 'tendency to lean more strongly when the exchange rate is moving in one direction than the other' (Longworth 1980, p. 284). Clearly, his point of departure is a symmetrical intervention behaviour of the Canadian monetary authorities. During the 1950s and early 1960s Canada was the only major industrialized country with a floating exchange rate. For this period, Longworth finds that depreciations were counteracted significantly stronger than appreciations. However, for the period June 1970—December 1977 no such asymmetries in the intervention behaviour are found. On average, the BoC bought (sold) 145 million US dollars for every one cent appreciation (depreciation) of the Canadian dollar *vis-à-vis* the US dollar in one month. Longworth notices that Artus (1976) and Quirk (1977) found an almost equal intervention response for the Bundesbank and the Bank of Japan (BoJ), respectively. The Canadian central bank does not appear to have tried to move the exchange rate closer to parity ($1 Can. = $1 US) or to PPP.

Argy (1982) discusses the theoretical and practical aspects of exchange rate management. He studies the intervention behaviour of Germany, Japan and the United Kingdom for the period March 1973 (for the UK: March 1972)—December 1979. By analysing the differences between gross and net interventions in a year, Argy infers the main objective of a country in that year.[3] In 1974 and 1975 net German and Japanese intervention was close to zero while gross intervention divided by the value of exports was around seven. Of course, this indicates that the central banks have tried to smooth exchange rate changes only. Gross intervention equalling net intervention, except for a sign, points to a one-way intervention effort to oppose persistent depreciation or to rebuild reserves after a period of large sales of foreign exchange as was the case in the United Kingdom during the years 1974—76 and in 1977, respectively. Estimation results for an intervention reaction function for the United Kingdom covering the period March 1972—October 1977 look as follows, with *t*-statistics shown in parentheses:

$$INV_t = \underset{(1.4)}{112.8} + \underset{(3.6)}{163.1}\ \dot{S}_t + \underset{(5.3)}{0.62}\ INV_{t-1}$$

$$R^2 = 0.53 \qquad \text{Durbin's } h \text{ statistic} = 0.00113 \tag{3.5}$$

It follows that every one percentage point change in the effective exchange rate was accompanied on average by an intervention effort by the Bank of England (BoE) amounting to 163 million US dollars in the month the exchange rate change occurred and 266 million US dollars thereafter. For the period November 1977—December 1979, the 'leaning' coefficient rises to 252.6. The coefficient for the lagged intervention variable becomes very small (0.08) and is no longer significantly different from zero. A regression with the percentage change of the *ex post* real effective exchange rate in place of the nominal effective rate yields moderately lower 'leaning' coefficients for both periods. In the case of Germany and Japan, the reaction function can explain only a quarter of intervention systematically. The coefficients for the percentage change in the effective rates are 115 and 210, respectively.

The explanatory power of the reaction functions estimated in König and Gaab (1982) over the period April 1973—July 1975 is satisfactory. The estimation results correspond to a large extent with those of the studies discussed above. However, estimates over later periods (1974—79, 1980—81) lose power dramatically.

Neumann (1984) takes up the challenge of trying to formulate and estimate an intervention reaction function which explains a considerable portion of observed Bundesbank intervention. Unlike König and Gaab (1982), Neumann (1984) has data at his disposal which give a precise coverage of the foreign exchange operations undertaken with the sole aim of influencing the exchange rate. Furthermore, Neumann applies non-linear Ordinary Least Squares (nl OLS) as the estimation technique. He tries to establish whether or not the Bundesbank shifts its priority to controlling the money stock when the uncertainty in the Deutsche Mark/US dollar market increases. Neumann derives an intervention reaction function by combining a policy loss function of the central bank with a flow model of the exchange rate. He distinguishes two major explanatory variables: the expected risk premium on DM assets and the difference between the actual exchange rate and a target level for the exchange rate. The target level specification for which the reaction function has the highest explanatory power can be written as follows:

$$\log S_t^T = \delta \log F_{t-1} + (1-\delta) \log S_t^{PPP} + \Delta\, RP_t + \mu_t \tag{3.6}$$

As in Artus (1976), PPP considerations (S_t^{PPP}) are taken into account. Of course, this comes down to stabilizing the real exchange rate. In an attempt to fight private speculation beforehand, the Bundesbank tries to compress the excess return on assets denominated in Deutsche Marks. This is done by revising the target rate in accordance with increases in the expected risk premium and movements in the lagged forward rate (F_{t-1}). It appears that for the more turbulent subperiod, September 1977—December 1981, Neumann's supposition of a shift in the trade-off in favour of money control is confirmed.

Following the approach taken by Longworth (1980), the empirical investigations in Bischofberger (1986) are aimed at establishing whether the central banks of the G-7 countries and Switzerland employed their intervention policy of 'leaning against the wind' symmetrically across periods of depreciation and appreciation of their own currencies *vis-à-vis* the US dollar and across periods with a rising and a falling effective exchange rate of their own currency. Bischofberger deflates the monthly change in a country's foreign exchange reserves by the sum of imports and exports in the current and eleven previous months. He does this in order to make the estimated coefficients and, thus, the intervention efforts, comparable across countries. Therefore, the implicit assumption is that the more open an economy is, the more opposed a central bank will be to short-term exchange rate fluctuations. In an attempt to detect (ir)regularities in the intervention behaviour of the individual countries, the 90 monthly observations are divided into four categories. A rise (fall) in the value of a currency in two consecutive periods is called a trend appreciation (trend depreciation) of the exchange rate *vis-à-vis* the US dollar. A rise (fall) in the value of a currency after a fall (rise) in the previous period is labelled non-trend appreciation (non-trend depreciation).

$$INV_t = \alpha_0 + \alpha_1 A_1 \dot{S}_t + \alpha_2 A_2 \dot{S}_t + \alpha_3 A_3 \dot{S}_t + \alpha_4 A_4 \dot{S}_t + \mu_t \qquad (3.7)$$

with: A_1 = 1 in case of trend appreciation, 0 otherwise
A_2 = 1 in case of non-trend appreciation, 0 otherwise
A_3 = 1 in case of trend depreciation, 0 otherwise
A_4 = 1 in case of non-trend depreciation, 0 otherwise

To be able to make comparisons across time, subsamples consisting of 30 observations each are created.[4] The three subsamples are July 1973—December 1975, January 1976—June 1978 and July 1978—December 1980. The Bundesbank appears to have carried out its interventions symmetrically. The intervention—trade ratio for a one per cent change in the effective exchange rate of the Deutsche Mark is 0.0023 (!) on average for all four categories of intervention. As König and Gaab (1982) experienced, the explanatory power of the estimated reaction function for the Bundesbank declines over time. The estimated reaction functions for the Banque de France (BdF) and the Banca d'Italia have low explanatory power and indicate that there was no systematic 'leaning against the wind' behaviour. For the sample as a whole, the BoE is found to have assigned systematically more weight to countering depreciations of the effective exchange rate of the pound and depreciations of the pound *vis-à-vis* the US dollar. However, the estimation results for the subsamples indicate that both trend and non-trend appreciations of the pound were a matter of concern of the British monetary authorities as well. The BoJ appears to have acted in a slightly asymmetrical way. The variable capturing non-trend depreciations of the yen *vis-à-vis* the US dollar has a coefficient significantly different from zero indicating at a 'leaning *with* the wind' behaviour. The directives of the Canadian Exchange Fund obliged the BoC to follow *grosso modo* the same intervention pattern as the Bank of Japan. However, compared to the BoJ the BoC carried out its sales and purchases of foreign currency more systematicallly and on a larger scale when measured by the intervention—trade ratio. To manage the liquidity position of the private banking system in Switzerland the central bank makes active use of foreign currency swap operations. This is, of course, reflected in the intervention reaction function. Apart from that, Bischofberger only finds the second subsample to show a systematic pattern of foreign exchange intervention. The Swiss National Bank appears to have tried to resist appreciations of the Swiss franc with respect to the US dollar which lasted longer than one month on the one hand, and to have supported depreciations which, *ex post*, were found to have lasted no longer than one month, on the other hand, both with particularly high intervention-trade ratios. The intervention behaviour of the monetary authorities of the United States can be explained systematically by means of a linear reaction function only for the last two subsamples. The estimation results indicate that the transactions in foreign exchange by the Federal Reserve System were mainly directed at curbing the rise of the effective exchange rate of the US dollar.

Kearney and MacDonald (1986) study the intervention behaviour of the BoE. They make a distinction between day-to-day dealings in foreign exchange to smooth transient fluctuations on the one hand, and interventions 'on a scale sufficient to maintain the rate of exchange at a level which differs from that which would otherwise have cleared the foreign exchange market' (Kearney and MacDonald 1986, p. 348) on the other hand. Quarterly data are used to test empirically whether the latter category of interventions was guided by a systematic 'leaning against the wind' policy. The OLS estimation result for the period April 1973—December 1982 looks as follows, with t-values in parentheses:

$$
\begin{aligned}
INV_t = &- 202.18 - 54.582\ (S_t - S_{t-1}) + 0.466\ INV_{t-1} \\
&\quad (0.46) \qquad (2.49) \qquad\qquad\qquad (3.10) \\
R^2 &= 0.34 \qquad DW = 1.88
\end{aligned}
\tag{3.8}
$$

It follows that on average the BoE bought (sold) 54.6 million US dollars for every pence the value of the US dollar dropped (rose) during the month the exchange rate change occurred and \$47.6 million thereafter. An IV estimation renders a higher but insignificant 'leaning' coefficient. A target exchange rate term defined analogously to that in Artus (1976) is insignificant.

Gärtner (1987) challenges the ruling consensus that central banks only employ a 'leaning against the wind' policy. He argues that large and persistent medium-term movements in the exchange rates are of major concern to international business. Therefore, exchange rate targeting should show up in the intervention reaction function as well. Before presenting an alternative specification of a reaction function for the Swiss National Bank (SNB) which meets with the apparent shortcomings of earlier investigations, Gärtner criticizes the way in which other studies deal with the simultaneity problem when estimating reaction functions. He claims to have found an appropriate solution for this problem. It involves employing the IV estimation technique using the percentage rate of change of the real exchange rate of the US dollar *vis-à-vis* the Deutsche Mark as an instrument to replace the percentage rate of change of the real exchange rate of the US dollar *vis-à-vis* the Swiss franc. Obviously, the real \$/DM rate is a cross-rate of the real \$/Sfr rate. Therefore, movements in both rates are correlated by definition. However, a direct consequence is that intervention by the German and Swiss central banks will be correlated as well. Therefore, Gärtner's assertion that changes in the real \$/DM rate do 'not itself respond in any relevant fashion to Swiss intervention' (p. 447) is a faulty one. This is the case particularly when the SNB subscribes to the conclusion reached in the following section that *coordinated* interventions conveying a news content constitute the only sort of interventions that have a chance to affect the rate of change of an exchange rate. Therefore, the real \$/DM rate is not a proper instrument for the reaction function. The estimation results are not reported here. An interesting aspect of the investigations by Gärtner is the flexible formulation of the reaction function. A distinction is made between the directions of change of the real exchange rate during a month. In addition to that the possibility is left open that the central bank takes into account whether the real Sfr/\$ rate is overvalued or undervalued. Thus, four cases are created.[5] It is found that appreciations of the Swiss franc which occurred while it was overvalued were opposed most strongly. Appreciations of the Swiss franc which took place when the currency was undervalued were tolerated. Analogous 'leaning against destabilizing wind' is detected for depreciations of the Swiss franc *vis-à-vis* the US dollar.

Gaiotti, Giucca and Micossi (1989) try 'to ascertain whether the intervention policies of 1985—87 entailed a departure from past practices' (p. 21). Their estimations cover the period 1974(4)—1987(12) or subperiods within this sample. They use monthly data. The estimating equation is obtained by substituting the equation which explains movements in the target exchange rate S_t^T, equation (3.2b) above, into the actual intervention reaction function. The intervention data used by Gaiotti, Giucca and Micossi are not very detailed. To account for changes in the reserve position of a central bank (INV_t) that do not directly result from interventions in the foreign exchange market, the trade balance (TB_t) is included as an explanatory variable in the reaction function. This is the main difference from the approach taken by Artus (1976). The most important IV estimation results for the Deutsche Bundesbank and the BoJ can be written as follows, with t-values in parentheses:

$$\underset{}{INV_t^{DBB}} = \underset{(-4.28)}{-1413.1} + \underset{(3.12)}{1479}\,(P_{GER}/P_{US}-1) + \underset{(0.44)}{17.96}\,TB_t + \underset{(3.77)}{2603.8}\,S_t + \underset{(3.46)}{169.4}\,\dot{S}_t$$

$$R^2 = 0.30 \qquad DW = 1.83 \tag{3.9a}$$

$$INV_t^{BoJ} = \underset{(-4.24)}{-3715.4} + \underset{(3.08)}{3148}\,(P_{JAP}/P_{US}-1) + \underset{(2.63)}{150.74}\,TB_t + \underset{(3.78)}{6974.8}\,S_t + \underset{(2.03)}{189.3}\,\dot{S}_t$$

$$R^2 = 0.39 \qquad DW = 1.69 \tag{3.9b}$$

The 'leaning against the wind' behaviour of the Bundesbank appears to have been stable throughout the period. The IV estimates imply that the German central bank, on average, bought (sold) 169 million US dollars for every one per cent appreciation (depreciation) of the Deutsche Mark *vis-à-vis* the US dollar during one month. However, estimation results for subperiods not reported here suggest that the steady appreciation of the US dollar from March 1980 until February 1985 was accompanied by a more than average intervention effort by the Bundesbank. The estimated coefficient for the variable capturing the 'leaning against the wind' intervention by the BoJ is larger (189 million US dollars) than that of the Bundesbank. Moreover, the

Japanese central bank intervened significantly less than average during the period of US dollar appreciation mentioned earlier. Furthermore, Gaiotti, Giucca and Micossi find that the BoJ from the middle of 1986 onwards rigidly tried to hold on to the prevailing exchange rate level. The reported IV estimates of the 'leaning' coefficients are significantly higher than the ones obtained with OLS. This can be explained by the fact that the former method accounts for the negative correlation between $\dot{S}_t$ and INV_t, while the latter does not. In view of the frequency of the data, one wonders whether the percentage rate of change of the spot rate from one period (month) to another ($\dot{S}_t$) can capture the 'leaning against the wind' character of the interventions adequately. A dummy variable which accounts for the coordinated interventions following the Plaza Agreement enters the estimated reaction functions of both the Bundesbank and the BoJ with a coefficient significantly different from zero. This indicates that the concerted action in October 1985 is one without precedent in the post-Bretton Woods era.

Honegger (1989) wants to let the data determine which explanatory variables have to be included in the intervention reaction function for the central banks of Canada, Germany, Japan, Switzerland and the United Kingdom. Honegger applies the vector autoregression (VAR) estimation technique to determine for each of the five countries whether or not lagged values of the level of intervention, the unemployment rate, the inflation rate, the percentage change of the exchange rate and the deviation of the exchange rate from PPP are significantly correlated with monthly intervention volumes for the period January 1974—December 1985. For none of the respective central banks does any other variable but lagged intervention and the percentage change of the exchange rate of the home currency *vis-à-vis* the US dollar appear to be correlated with the volume of intervention. However, Honegger argues that lasting deviations of a country's effective exchange rate from PPP are far more damaging for the domestic economy than short-term exchange rate volatility. Therefore, it should appear from the reaction functions that central banks take into account whether or not a currency is over- or undervalued and act differently when the exchange rate moves towards PPP as compared to cases in which the exchange rate moves away from the equilibrium rate implied by PPP. Honegger contends that, as actual monthly foreign and domestic inflation rates (necessary to compute the PPP rate) are available only with a certain lag, it is unknown whether a currency is over- or undervalued during a particular month. He computes the *ex ante* PPP rate based on the assumption that the equilibrium exchange rate follows a first order autoregressive process. Four variables are constructed. Each represents the percentage change of the home currency *vis-à-vis* the US dollar during one month in discrete cases:

V_1 appreciation during undervaluation
V_2 depreciation during overvaluation
V_3 depreciation during undervaluation
V_4 appreciation during overvaluation

OLS estimation results for the Deutsche Bundesbank (DBB) and the Bank of Japan (BoJ) look as follows:

$$INV_t^{DBB} = \underset{(0.86)}{-0.006} \underset{(4.36)}{-0.515}\, V_1 \underset{(1.22)}{-0.207}\, V_2 \underset{(1.65)}{-0.501}\, V_3 \underset{(4.64)}{-0.872}\, V_4 + \underset{(1.10)}{0.083}\, INV_{t-1}^{DBB}$$

$$R^2 = 0.26 \qquad \text{Durbin's } h = -4.93 \qquad SER = 0.034 \qquad (3.10a)$$

$$INV_t^{BoJ} = \underset{(0.26)}{0.002} \underset{(0.32)}{-0.064}\, V_1 \underset{(2.52)}{-0.515}\, V_2 \underset{(1.29)}{-0.509}\, V_3 \underset{(5.17)}{-1.022}\, V_4 + \underset{(4.25)}{0.304}\, INV_{t-1}^{BoJ}$$

$$R^2 = 0.34 \qquad \text{Durbin's } h = -2.65 \qquad SER = 0.037 \qquad (3.10b)$$

As before, t-values are in parentheses. *SER* denotes the standard error of regression. It appears that the DBB only tried to counteract appreciations of the Deutsche Mark *vis-à-vis* the US dollar. It should be noted that this finding not only applies to months in which the DM was overvalued (V_4) but also to months in which the DM was undervalued (V_2), albeit with a smaller 'leaning' coefficient. Given that the Deutsche Mark was undervalued, a one percentage point appreciation of the DM on average led the Bundesbank to buy US dollars to an amount equivalent to 0.515 per cent of the Bundesbank's foreign exchange reserves. Based on the estimation results Honegger concludes that the Bundesbank undertook its interventions at least partly to enhance the international competitiveness of German industries. For the BoJ 'leaning against the wind' behaviour is found only during months in which the yen was overvalued. Most noticeable in this respect is the systematic selling of foreign exchange in return for yen when the yen 'threatened' to move towards the (computed) equilibrium value. The BoC appears to have carried out its interventions symmetrically across all four cases. The amount of intervention during months of appreciation was three times as large as during months of depreciation. For the BoE the results suggest that interventions were mainly guided by the pursuit of domestic price stability. The operations in the foreign exchange market were directed one-sidedly at opposing depreciations of the pound *vis-à-vis* the US dollar. The estimation results for the SNB are similar to the ones found by Gärtner (1987).

Eijffinger and Gruijters (1991) have daily data of intervention by the Bundesbank and the Federal Reserve System at their disposal. This allows them to test for an other intervention strategy: countering erratic fluctuations and 'leaning against the wind' over shorter periods than one month. To take account of intra-daily exchange rate movements, Eijffinger and Gruijters include in their estimation the opening (primo), fixing, and closing (ultimo) rates of every trading day at the Frankfurt foreign exchange market. These variables are denoted by S_t^P, S_t^F and S_t^U, respectively. It appears that on average one-fifth of Bundesbank and Federal Reserve interventions on day t can be explained by the difference between day t's opening spot rate of the US dollar in terms of DM and the five days moving average of the opening, fixing and closing rate. For September 1985 estimation results indicate that the Bundesbank pursued a 'leaning *with* the wind' policy. A closer inspection of the data revealed that all observed US dollar sales were carried out after the establishment of the Plaza agreement had shifted the market sentiment in favour of a depreciation of the US dollar. The coordination of exchange market intervention by the Bundesbank and the Federal Reserve System is investigated by adding intervention by the Federal Reserve as an additional explanatory variable of the Bundesbank's reaction function. The estimated coordination coefficient is significantly different from zero in five out of eight months in which both central banks intervened. However its value is unstable. This points at a changing degree of coordination. To test the effect of exchange market uncertainty on interventions the 'leaning against the wind' variable is adjusted for the variance of the opening, fixing and closing rates of the US dollar in terms of the DM in the past five days. The estimation results for the reaction function of the Bundesbank's interventions (INV_t^{DBB}) in October 1987 are as follows, with t-values in parentheses

$$INV_t^{DBB} = \underset{(-0.10)}{-0.003} - \underset{(-5.47)}{1321.7}\ \sigma_5^2 \left[S_t^P - \frac{1}{15} \sum_{n=1}^{5} S_{t-n}^{P/F/U} \right] \tag{3.11}$$

$$\text{with } \sigma_5^2 = \sum_{n=1}^{5} \left[S_{t-n}^{P/F/U} - \frac{1}{15} \sum_{n=1}^{5} S_{t-n}^{P/F/U} \right]^2, \quad \bar{R}^2 = 0.580,\ DW = 1.760$$

Eijffinger and Gruijters find that in months with large exchange rate fluctuations the smoothing coefficient as well as the explanatory power of the reaction function are larger than in months with small fluctuations. This indicates that the Bundesbank and the Federal Reserve System accept their responsibility and do not pull back when uncertainty in the foreign exchange market grows, contrary to the empirical findings of Neumann (1984).

Dominguez and Frankel (1993a) test whether daily Bundesbank and Federal Reserve intervention in the \$/DM market was geared towards a PPP-implied target level of the \$/DM rate. In addition to that, they test whether the German and US central banks tried to keep the \$/DM rate close to target levels to which, according to Funabashi (1988), the G-5 countries had agreed at successive summit meetings during the period 1985—89. For the post-Louvre period, February 1987—December 1990, the Federal Reserve is not found to have 'leaned against the wind'. Rather, action was taken when the dollar wandered away from its target rate. IV estimation results for this period, which comprises 900 observations, can be written:

$$\underset{}{INV_t^{FED}} = \underset{(-2.69)}{-14.71} + \underset{(0.29)}{34.71\ \Delta s_t} - \underset{(-0.66)}{7.73\ \Delta s_{t-1}} + \underset{(4.77)}{5.20\ (s_t - s_t^{PPP})} + \underset{(13.00)}{0.52\ INV_{t-1}^{FED}}$$

$$R^2 = 0.35 \qquad (3.12)$$

Accordingly, a one per cent rise in the value of the DM in terms of US dollars above the PPP rate, on average, led the Federal Reserve to buy US \$5.2 million. The estimation result for a reaction function with the alternative target specification is almost identical. The intervention effort for a one per cent deviation from the target rates given in Funabashi (1988) is US\$ 4.59 million. For the Bundesbank, the overall explanatory power of the estimated intervention reaction functions is lower. Intervention data are available from September 1985 to December 1988. Again, no systematic 'leaning against the wind' behaviour is found. The PPP target performs better than the Funabashi target. However, the intervention coefficient implies that for the post-Louvre period, February 1987—December 1988, a one per cent appreciation of the DM above the PPP rate, on average, led the Bundesbank to buy only US \$1.8 million.

3.3 EFFECTIVENESS OF INTERVENTION

This section discusses the results of empirical research carried out to ascertain the effectiveness of foreign exchange market intervention undertaken since 1973.

A purchase (sale) of foreign exchange by a central bank leads, *ceteris paribus*, to an increase (decrease) in the reserve position of the private banking system as a whole. The induced loosening (tightening) of the domestic money market results in an increase (decrease) in the money stock. In the structural exchange rate models discussed in the previous chapter a depreciation (appreciation) of the domestic currency is the immediate consequence. Nearly all empirical investigations disregard this monetary channel because it can be argued that this channel applies to monetary policy rather than exchange rate policy. Of course, this argument may be arbitrary.

To prevent the money stock from increasing (decreasing) the monetary authorities can sterilize the effect of the exchange market intervention by selling (buying) short-term domestic assets to (from) the banking system leaving the monetary base of the country unchanged. In the previous chapters two main channels of influence of sterilized interventions were distinguished. When investors do not view otherwise identical government bonds denominated in different currencies as perfect substitutes, a disturbance of the portfolio balance caused by a sterilized purchase of bonds denominated in the relatively 'risky' currency leads to a rise in the value of the 'risky' currency.

Attention has been paid to the effectiveness of interventions via the portfolio balance channel because this channel, if operative, constitutes a tool of exchange rate policy which is independent from monetary policy. However, the enormous growth in financial market turnovers during the last decades seems to have diminished the potential for central banks to cause a significant imbalance in investors' portfolios. For this reason current research focuses more on the expectations channel.

Sterilized intervention could influence exchange rates by providing new information about future monetary policy to an otherwise efficient (semi-strong form) market. Moreover, it could simply alter private exchange market participants' expectations in an informationally inefficient market.

As was argued in the previous chapter, the portfolio balance channel can only be effective if the risk premium on assets denominated in domestic currency, (RP^D) in equation (2.38), does not equal zero. Problems arise however when one wants to calculate the risk premium. Various attempts have been made using different kinds of expectations formations (see, on the problem of estimating econometrically the portfolio balance model, Tryon 1983 and Weber 1986). Another complication lies in the fact that the effect of central bank interventions is absorbed immediately in the movements of the exchange rate. To get a clear view of the actual effectiveness one should be able to compare these movements with the fluctuations in the exchange rate that would have occurred in the absence of intervention. Furthermore, it can be argued that the estimations are rather partial as most of the time intervention will be accompanied by other measures of monetary policy, for instance interest rate policy.[6]

The remainder of this section reviews a number of empirical investigations into the effectiveness of exchange market intervention. Their main characteristics are summarized in Table 3.2.

Branson, Halttunen and Masson (1977, 1979) estimate a reduced-form portfolio balance model. Movements in the spot rate of the Deutsche Mark in terms of US dollars (S_t) are related to movements in US and German stocks of money ($M1_t^{US}$, $M1_t^{G}$) and stocks of net foreign assets (FP_t^{US}, FP_t^{G}). Sterilized foreign exchange market interventions have an impact on the volume of a country's net foreign assets, but leave the money stock unchanged. Thus, if accurate data on privately held net foreign assets are available, it is possible to detect the effect of sterilized interventions without having the problem of finding a proxy for exchange rate expectations. Consistent estimates look as follows, with *t*-values in parentheses:

$$\begin{aligned} S_t = \underset{(-0.1)}{-4.852} - \underset{(-1.7)}{0.062}\, M1_t^{G} + \underset{(2.8)}{0.092}\, M1_t^{US} + \underset{(1.7)}{0.676}\, FP_t^{G} - \underset{(-1.9)}{0.398}\, FP_t^{US} \end{aligned}$$

$$\bar{R}^2 = 0.937 \qquad DW = 1.349 \qquad RHO = 0.868\ (14.0) \qquad (3.13)$$

RHO denotes the estimated first-order autocorrelation coefficient. All coefficients have the correct sign. A point estimate in Branson et al. (1977) suggests that a sterilized purchase by the Bundesbank of US \$1 billion on average caused the DM to depreciate by 0.185 cent. However, comparing Branson et al. (1977) and Branson et al. (1979) raises doubts about the robustness of this effect.

To find some evidence on the extent to which sterilized intervention was practiced by the Bundesbank during 1975—81, Obstfeld (1983) estimates a domestic credit reaction function. The estimated coefficients indicate that only a small fraction of any change in reserves was allowed to affect the monetary base. In contrast to Branson et al. (1977, 1979), Obstfeld focuses on a structural portfolio balance model of German asset markets. The estimation results indicate that home and foreign demand for DM-denominated bonds only adjusted slowly to their long-run levels. To assess the effects of sterilized as compared to non-sterilized intervention on the exchange rate, the empirical model is simulated under the assumption that agents have perfect foresight concerning future exchange rate movements. Many events which impinge on the exchange rate are in fact unanticipated. Consequently, the historical exchange rate path is not a proper reference for the simulation results. Therefore, the results of a simulation giving the exchange rate's perfect-foresight path in the absence of intervention serve as a benchmark. The results of the simulation experiments imply that a foreign exchange sale by the Bundesbank that decreases the German monetary base by DM 13.25 billion (in 1979: 10 per cent) causes an immediate 3.0 per cent appreciation of the DM *vis-à-vis* the US dollar relative to its benchmark value. By contrast, the simulated effect on the exchange rate of an unanticipated but transitory sale of DM 13.25 billion which is accompanied by an open market purchase of DM-denominated bonds of equal proportion by the German central bank is a mere 0.04 per cent. However, the apparent ineffectiveness in simulation experiments with monthly data does 'leave open the possibility that sterilised foreign exchange market intervention has significant but short-lived exchange rate effects that disappear within a month' (Obstfeld 1983, p. 185).

Loopesko (1984) constructs a series for realized one-day foreign exchange market profits, r_t, taking into account the usual two-day lag in delivery on spot foreign exchange contracts:

$$r_{t-2,\, t+1} = (i_t^{US} - i_t^*) - (s_{t-1} - s_{t-2}) \tag{3.14}$$

s_t is the logarithm of the spot rate of a G-7 currency in terms of US dollars, i_t^{US} and i_t^* are overnight US dollar and G-7 currency Eurodeposit rates, respectively. Realized profits calculated this way reflect both the expected risk premium and any spot rate forecast error. The joint hypothesis of perfect substitutability of assets denominated in different currencies and of the 'efficient' working of the foreign exchange market is rejected because previously observable variables (e.g., cumulated interventions, lagged values of realized profits and the exchange rate) are found to be significant determinants of realized profits. The results of a second (F-)test lead Loopesko to conclude that 'the predictable component of realized profits can be identified with a risk premium, and hence that sterilized intervention can affect the exchange rate through a portfolio balance channel' (Loopesko 1984, p. 267). However, interventions are only one out of many factors that determine demand and supply conditions on the foreign exchange market and therefore changes in the risk premium. Loopesko's investigation of the 'extra effectiveness' of coordinated interventions is hindered by a lack of data as well as difficulties in interpreting the data. She finds some evidence of a more than proportionate effect of coordinated US and narrowly defined German intervention.

Rogoff (1984) expects the risk premium on assets denominated in Canadian dollars to be positively correlated with the relative supply of Canadian dollar- (A_t) versus US dollar- (A_t^*) denominated outside assets, including the monetary base of Canada and the United States, respectively:

$$i_t^{CAN} - i_t^{US} - \Delta s_t^e = \alpha_0 + \alpha_1 \,(A_t \,/\, s_t A_t^*) + \mu_t \tag{3.15}$$

Rogoff postulates rational expectations. This enables him to replace the expected exchange rate change by the *ex post* exchange rate change:

Table 3.2 The effectiveness of foreign exchange market intervention. Some characteristics of the studies reviewed

	Period	Data	Estimation technique	Definition of intervention	Exchange rate	Intervening central bank
portfolio balance channel						
Branson et al. (1977, 1979)	1971(8)—1976(12)/1978(3)	monthly	2 SLS	international reserves of Germany (in US dollars) minus cumulated SDR allocations (p. 323)	spot rate of the DM in terms of US dollars, (index: 1970 = 100)	DBB
Obstfeld (1983)	1975(1)—1981(10)	monthly	2 SLS	change in the Bundesbank's net foreign assets minus the change in foreign reserve valuation (p. 185)	spot rate of the US dollar in terms of Deutsche Marks (p. 186)	DBB
Loopesko (1984)	1975(5)—1981(11)	daily	OLS	interventions of the individual G-7 countries (in millions of US dollars)(p. 27)	(log of the) spot rate of the G-7 currencies in terms of US dollars	CBs of the G-7
Rogoff (1984)	1973(3)—1980(12)	weekly	2S 2SLS	changes in the Canadian Ex-change Fund account, SDR allocations and bookkeeping valuation effects netted out (p.148)	(log of the) spot rate of the US dollar in terms of Canadian dollars	Bank of Canada
Danker et al. (1985)	1975(2)—1981(12)	monthly	nl 2SLS	no intervention data used	DM/$, yen/$ and $/Can$ spot rate	
Kearney and MacDonald (1986)	1973(II)—1982(IV)	quarterly	OLS & IV	changes in foreign exchange reserves (p. 363)	spot exchange rate of the US dollar in terms of sterling (p. 350)	Bank of England
Portfolio balance — and expectations channel						

Dominguez and Frankel (1993a,b)	1982(11)—88(12)	daily	IV	consolidated daily official foreign exchange transactions in the $/DM market at current market values excluding passive interventions (p. 72)	spot rate of the Deutsche Mark in terms of the US dollar	DBB & FED
Dominguez (1990)	1985(1)—1987(12)	daily	OLS	German and US data: see Dominguez and Frankel (1993a,b). The author constructs a dummy variable for Japanese intervention (p. 310)	spot rate of the DM and the yen in terms of US dollars (p. 140)	DBB FED BoJ
Expectations channel						
Humpage (1988)	1984(8)—1987(8)	dummies with value one on days the Fed intervened and with value zero on days the Fed did not intervene	OLS	'intervention dummies are constructed from internal documents on US intervention' (p. 4)	— log of the spot rate of the US dollar in terms of DM — log of the spot rate of the US dollar in terms of yen	FED
Eijffinger and Gruijters (1992)	1985(2)—1988(8)	daily	OLS	active intervention inside the US dollar/DM market aimed at influencing the spot rate of the US dollar in DM (in billions of DM) (p. 2)	spot rate of the US dollar in terms of DM	DBB & FED

$$s_{t+1} = s_{t+1}^{e} + \Theta_{t+1} \tag{3.16}$$

where Θ_{t+1} is a forecast error which is uncorrelated with any information dated period t or earlier. The very disappointing estimation results are accompanied by the 'plausible interpretation that there is a time-varying exchange risk premium but one that cannot be affected by sterilized intervention' (Rogoff 1984, p. 141).

Danker et al. (1985) study the degree of substitutability of bonds denominated in Deutsche Marks, Japanese yen, and Canadian dollars with those in US dollars. Danker et al. argue that direct estimation of the asset-demand equations forming the portfolio balance model 'may not yield accurate estimates of the degree of substitutability when the true degree of substitutability is quite high' (Danker et al. 1985, p. 1). Therefore, inverted bond-demand equations are estimated with non-linear two-stage least squares (nl 2SLS). The dependent variable in these equations is the risk premium. Both under the assumption of static as well as rational exchange rate expectations, perfect substitutability implies that the risk premium should be uncorrelated with explanatory variables suggested by the portfolio balance model (short-term interest rate differentials, real income, real wealth and stocks of bonds). For Germany the estimation results based on monthly data clearly point to the rejection of perfect substitutability. However, the results are inconsistent with the portfolio balance model. The same applies to the results for Canada obtained with quarterly instead of monthly data. For Japan, when assuming rational expectations, the hypothesis that all the coefficients in the inverted-bond equation are equal to zero is not rejected using monthly data. Having established this, Danker et al. report estimation results for the original bond-demand equations. They only consider whether (the sign of) the estimated parameters of these equations are consistent with the portfolio balance model. Probably, the disappointing results of earlier empirical investigations prevented them from formal hypothesis testing. The consequence is that 'the degree of success obtained is largely a matter of judgment' (Danker et al. 1985, p. 12).

Kearney and MacDonald (1986) replicate the study by Obstfeld (1983). Central to their investigations is a portfolio balance model for the United Kingdom estimated with quarterly data from the second quarter of 1973 through to the fourth quarter of 1982. Kearney and MacDonald examine the potency of sterilized and non-sterilized interventions carried out by the Bank of England based on the results of various policy simulations with the model. Their results contrast with Obstfeld's findings for Germany. A non-sterilized sale of US dollars worth £10 billion (in 1976: 10 per cent of the UK monetary base) is found to cause a 7.9 per cent appreciation of the pound *vis-à-vis* the US dollar. Furthermore, a sterilized sale of equal magnitude raises the value of sterling by 3.2 per cent. Kearney and MacDonald contend that the effectiveness of a sterilized intervention not only depends upon the degree of substitutability between domestic and foreign assets but also on the degree of capital mobility whereby the instantaneous achievement of portfolio balance is regarded as a necessary and sufficient condition for perfect capital mobility. Kearney and MacDonald impute the effectiveness of sterilized intervention appearing from the simulation results for the UK to the restrictions on capital mobility in the 1970s.

Dominguez and Frankel's initial (1990) study attempts to disentangle the influence of the portfolio and the expectations channel. The estimation results concerning the portfolio effect of intervention are contained in Dominguez and Frankel (1993b). The estimation results for the expectations channel figure prominently in Dominguez and Frankel (1993a). Regarding the portfolio effect, again, the main idea is that sterilized interventions are effective if they are able to change the risk premium. Dominguez and Frankel (1993b) estimate a portfolio balance equation that is consistent with mean-variance optimization:

$$i_t^{DM} - i_t^{\$} + \hat{s}_{t+1}^{e} - s_t = \alpha_0 + \alpha_1 v_t + \alpha_2 v_t x_t + \mu_t \tag{3.17}$$

where $\hat{s}_{t+1}^{e}$ is the log of the one-period ahead survey expectation for the \$/DM spot rate. Contrary to Rogoff (1984), Dominguez and Frankel do not invoke the methodology of rational expectations. Instead, expected future exchange rates are represented by data from surveys of expectations among private exchange market participants.[7] v_t is a measure of the variance of the change in the exchange rate, x_t is the ratio of the total quantity of DM assets to the sum of the total quantities of DM and US dollar assests, both measured in dollars, and μ_t is an error term. Dominguez and Frankel report OLS and IV estimates of the risk premium equation. Federal Reserve and Bundesbank intervention cumulated from the beginning of the sample period expressed as a percentage of wealth (i.e., the sum of DM and dollar assets) is a statistically significant determinant of the risk premium on DM-denominated assets. This leads Dominguez and Frankel to conclude that over the period considered, sterilized interventions were effective.

In their (1993a) study Dominguez and Frankel provide evidence for the effectiveness of intervention in three ways. The first two are clearly hindered by the familiar problem of reversed causality or simultaneity. The third is based on some unrealistic underlying assumptions. The first way of showing that intervention by the Federal Reserve and the Bundesbank during the period 1985—90 was effective involves distinguishing eleven 'intervention episodes'. These are non-overlapping periods of three to eight months during which both central banks tried to influence the DM/$ rate. It is found that

> generally, in the month following the end of an intervention episode, the mark—dollar exchange rate moved in a manner consistent with the intervention operations. When intervention operations were in support of the dollar, the dollar appreciated against the mark in the month following the end of the operations. Likewise, when central banks sold dollars, the dollar depreciated against the mark in the month following the end of the intervention episode. (Dominguez and Frankel 1993a, p. 95)

It should be clear, however, that the comparison of movements in the Deutsche Mark/US dollar exchange rate in the months before and after eleven periods of intervention by the Federal Reserve and the Bundesbank is a far cry from direct evidence of interventions *causing* exchange rate movements. 'News' hits the forex market almost continuously. Consequently, a lot may have happened in these periods of intervention which each lasted three to eight months (including *inter alia* changes in monetary and fiscal policies in the countries concerned). The results of Dominguez and Frankel can be interpreted with equal force as evidence that the central banks withdrew from the foreign exchange market once unfavourable exchange market pressure had subsided *irrespective of the precise cause*. At best, these results shows that the old wisdom that what goes up must come down also applies to exchange rates. The second way of showing that intervention by the Federal Reserve and the Bundesbank during the period 1985—90 was effective is not less controversial. After 'showing' that extended periods of intervention moved the Deutsche Mark/US dollar exchange rate in the desired direction, Dominguez and Frankel move on smoothly to argue that intervention is best conducted sparingly — which in itself is a contradiction. More importantly, however, the interpretation of the crucial Tables 7.1—7.6 which are said to contain evidence in favour of the effectiveness of intervention is fallacious. The crucial coefficients on which the provoking conclusions are based are always 'incorrectly signed'. The estimated equation looks as follows:

$$s_t - s_{t-1} = \gamma_0 + \gamma_1\, NEWS_t + \gamma_2\, REPINT_t + \gamma_t\, SECINT_t + \mu_t \quad (3.18)$$

where s_t is defined as the dollar price of one Deutsche Mark. Consequently, a rise in the exchange rate is equivalent to a depreciation of the US dollar. $NEWS_t$, $REPINT_t$ and $SECINT_t$ are (+1, 0, —1) dummy variables. $NEWS_t$ is set equal to +1 if there were official announcements other than those about intervention that are favourable to the US dollar, —1 in the case of official announcements against the dollar, and 0 if there were no such announcements. Analogously, $REPINT_t$ is set equal to +1 if there were reports of central bank intervention in support of the dollar. $SECINT_t$ is set equal to +1 if there were no reports of intervention when a central bank in fact intervened in support of the dollar. Based on the definition of the explanatory variables, the coefficient γ_1 is expected to be negative with official announcements in support of the dollar leading to a stronger dollar and, hence, a lower dollar price of one Deutsche Mark. Analogously, the coefficient γ_2 is also expected to be negative. Purchases of US dollars ($REPINT_t$ = +1) should lead to a fall in the US dollar price of one Deutsche Mark. Interventions which were not reported in the press are not expected to have had an effect ($\gamma_3 = 0$). The $NEWS_t$ dummy turns out to be statistically different from zero and to have the expected negative sign irrespective of the precise specification of the estimated effectiveness equation. However, the coefficient γ_2 is systematically wrongly signed ($\gamma_2 > 0$). Dominguez and Frankel (1993a) admit this several times (e.g., 'the variable that captures reports of central bank intervention is significant but incorrectly signed' (p. 116)). Obviously, this invalidates any conclusions concerning the effectiveness of intervention to be drawn from the estimation results. In fact, equation (3.18) seems to be a degenerated intervention reaction function which indicates that positive changes in the exchange rate ($\Delta s_t > 0$) trigger official purchases of US dollars ($\gamma_2 > 0$, $REPINT_t$ = +1). Yet, Dominguez and Frankel estimate several more detailed specifications of equation (3.18) to detect differences in the effect of initial versus subsequent intervention and coordinated versus non-coordinated intervention. They conclude that both initial interventions and coordinated interventions had large effects.

Dominguez and Frankel (1993a) provide a third piece of evidence in favour of the effectiveness of interventions carried out by the Federal Reserve and the Bundesbank during the period 1985—90. It is closely linked to the results in their (1993b) study. The authors try to quantify the effect of intervention on the spot rate. They make use of the 'knowledge that the portfolio share allocated to mark assets, x_t, is a function of the risk premium which is in turn a function of expected depreciation $\Delta\hat{s}^e_{t+1}$, which is in turn a function of news [about intervention]' (Dominguez and Frankel 1993a, p. 132). The expected exchange rate change is a crucial component of the risk premium. Therefore, Dominguez and Frankel try to establish the impact of publicly known intervention and interventions carried out anonymously on market participants' expectations. They estimate the following equation:

$$\hat{s}^e_{t,k} - \hat{s}^e_{t-j,k} = \alpha_0 + \alpha_1 (s_t - s_{t-j}) + \alpha_2 (s_t - \hat{s}^e_{t-j,k}) + \\ + \alpha_3 \, NEWS_t + \alpha_4 \, REPINT_t + \alpha_5 \, SECINT_t + \epsilon_t \qquad (3.19)$$

where $\hat{s}^{e}_{t-j,k}$ is the log of the *k*-days ahead expectation for the \$/DM spot rate which is collected *j* days ago. The dependent variable in equation (3.19) is the percentage revision in the survey prediction of the *k*-days ahead dollar—mark spot rate from time *t—j* to time *t*. It is assumed that investors expect the trend in exchange rate movements over the previous *j* days to carry on during the following *k* days. Furthermore investors are expected to redress their expectations when it becomes known that central banks change their exchange rate policy. The dummy variable *NEWS* captures this effect. The dummy variables *REPINT* and *SECINT* were defined above. Estimation results for the period October 1982—October 1984 are not very interesting. As is well known the monetary authorities in the United States hardly intervened during that period. For the period October 1984—December 1987 it appears from the estimation results that newspaper reports of exchange rate policy announcements (*NEWS*) and central bank intervention (*REPINT*) in support of the dollar tended to lower expectations of the future \$/DM exchange rate. Secret interventions are found to have no effect on expectations. Dominguez and Frankel (1993a) attempt to quantify the ultimate effect of interventions on the spot rate by carrying out some tentative calculations. On the assumption that interest rates in Germany and the United States are unaffected by an intervention operation, a publicly known non-sterilized Bundesbank purchase of \$100 million against the mark leads to a 1.581 per cent appreciation of the US dollar *vis-à-vis* the mark.

Dominguez (1990) investigates whether *ex post* one-day, thirty-day and ninety-day excess returns in the US dollar—Deutsche Mark and US dollar—Japanese yen market are related to unilateral and coordinated intervention by the Bundesbank, the Federal Reserve System and the Bank of Japan.[8] Five distinct episodes are estimated: January 1985—March 1985, September 1985—December 1985, September 1986—January 1987, February 1987—June 1987 and October 1987—December 1987. Dominguez claims to focus on the possible signalling effect of official intervention, i.e. the capacity of intervention to influence exchange rates by providing information about the future conduct of monetary policy. She states that this effect does not rely on the existence of a risk premium. Yet, her method for estimating the signalling effect does. The estimation results for the five periods of coordinated G-3 intervention indicate that the expectations channel was the main channel through which intervention affected the excess returns. For each subperiod the results are in line with what could be expected on the basis of Dominguez' description of the policy announcements made by the G-3 monetary authorities and the press accounts which reflect how these announcements were interpreted by private exchange market participants. For example, the Plaza Agreement was understood by the market to be specifically initiated by the United States.

This was judged to reflect a definitive break from the previous policy and the market was very alert to US intervention. By contrast, no particular attention was paid to Bundesbank intervention immediately after the Plaza Agreement. The German central bank had already intervened on a large scale in the first quarter of 1985 and its intentions apparently had not changed since then. The estimation result for the equation relating the *ex post* one-month US dollar—DM excess return, taking into account the usual two-day lag in delivery on spot contracts, $r_{t-2,\,t+21}$, to the interventions conducted three days before the survey of exchange rate expectations for the period September 1985—December 1985 is reported here, with t-values in parentheses:

$$\underset{}{r_{t-2,\,t+21}} = \underset{(-5.18)}{-\,40.44} \underset{(-2.55)}{-\,0.12\, INV_{t-3}^{FED}} \underset{(-1.81)}{-\,0.16\, INV_{t-3}^{DBB}} \underset{(-2.16)}{-\,0.51\, INV_{t-3}^{C}} \qquad (3.20)$$

$$R^2 = 0.09$$

The excess return relates to Eurocurrency deposits with a time to maturity of one month, i.e. twenty-one trading days. Analogous to Eijffinger and Gruijters (1992) Dominguez defines coordinated intervention (INV^C) observations as the sum of Federal Reserve and Bundesbank intervention observations on days that both banks intervened in the same direction. A coordinated sale of one million US dollars on average increased the annualized US dollar—Deutsche Mark return differential by 51 basis points. The results change from subperiod to subperiod. In some instances, statistically significant but wrongly signed coefficients are obtained, reflecting the fact that the interventions were not accompanied by credible policy announcements. For the three-year period under consideration coordinated intervention is found to have had a significantly different and longer-term influence on market expectations than unilateral intervention. This indicates that it was not the size of intervention that counted, which is compatible with the portfolio balance channel, but the source of intervention pointing to the relevance of the expectations channel.

In the analysis of Humpage (1988) it is not the volume of intervention that counts. The mere fact that the Federal Reserve Bank entered the market is of crucial importance. To emphasize the search for the 'news'-effect of interventions, Humpage constructs dummy variables to distinguish between initial and subsequent interventions. The former type refers to interventions carried out following a period of at least five days without intervention. The latter type is the complement of the former. For the period August 1984—August 1987 Humpage distinguishes three subperiods in which the attitude of the Federal Reserve System towards intervention showed fundamental differences. Initial purchases of DM and yen directly following the Plaza meeting (represented by the dummy variables D^1 and D^3, respectively) significantly contributed to a depreciation of the US dollar against the DM and the yen respectively. Subsequent intervention (represented by the dummy variables D^2 and D^4, respectively) did not produce a significant effect. Estimation results for the 75 trading days between August 23, 1985 and December 9, 1985 can be written as follows, with t-values in parentheses:

$$\underset{}{s_t^{\mathrm{DM/\$}}} = \underset{(-6.455)}{-0.052\, D_t^1} + \underset{(0.824)}{0.002\, D_{t-1}^2} + \underset{(1003.3)}{0.999\, s_{t-1}^{\mathrm{DM/\$}}} \qquad R^2 = 0.970 \tag{3.21a}$$

$$s_t^{¥/\$} = \underset{(-4.996)}{-0.027\, D_t^3} - \underset{(-0.101)}{0.0002\, D_{t-1}^4} + \underset{(5272.1)}{0.999\, s_{t-1}^{¥/\$}} \qquad R^2 = 0.987 \tag{3.21b}$$

Initial intervention carried out following the establishment of the Louvre Agreement did not have an effect on the opening rates of the US dollar *vis-à-vis* the DM ($s_t^{\mathrm{DM/\$}}$) and the yen ($s_t^{¥/\$}$) in New York due to conflicting statements on the direction of US policy. Humpage concludes that intervention can have an effect on exchange rate movements taking into account that 'the size and duration of any announcement effect seems to depend on the extent to which the intervention creates expectations of changes in monetary and fiscal policies' (Humpage 1988, p. 15).

Eijffinger and Gruijters (1992) assume the market for foreign exchange to be highly efficient. In that case, effective interventions will influence exchange rate movements immediately — that is, within the same day — by altering the expectations of market participants. Therefore, to test for the effectiveness of intervention Eijffinger and Gruijters relate the closing rate of the US dollar in DM at the Frankfurt foreign exchange market on day t (S_t^U) to spot market intervention by the Bundesbank (INV_t^{DBB}) and the Federal Reserve (INV_t^{FED}) during day t. Other explanatory variables are day t's opening DM/dollar rate (S_t^P), the lagged closing rate (S_{t-1}^U) and changes in the interest differential between one-month Euro-DM deposits and one-month Eurodollar deposits in London during day t ($\Delta(i^{DM} - i^{\$})_t$). Interventions appear to have had a significant influence on the US dollar—DM exchange rate during only one out of eight estimated periods of about six months. The estimation results for the period February 1985—June 1985 are as follows, with t-values in parentheses:

$$
\begin{aligned}
S_t^U = {} & \underset{(-0.089)}{-0.0063} + \underset{(8.650)}{0.9037}\, S_t^P + \underset{(0.948)}{0.0988}\, S_{t-1}{}^U - \underset{(-0.678)}{2.0196}\, \Delta(i^{DM} - i^{\$})_t + \\
& + \underset{(2.741)}{0.0196}\, INV_t^{DBB} - \underset{(-1.188)}{0.0606}\, INV_t^{FED} \qquad \bar{R}^2 = 0.9589 \quad DW = 2.0786
\end{aligned} \tag{3.22}
$$

The estimation results suggest that a sale of US dollars worth DM 1 billion carried out by the Bundesbank on average caused the US dollar to depreciate *vis-à-vis* the DM by 2 Pfennig during the day on which the intervention took place. The announcement of unexpected US trade balance figures proved to have outweighed the effect of interventions in other periods. Eijffinger and Gruijters conclude that a selective intervention strategy and a careful timing of the interventions can enhance their effectiveness. Coordinated interventions and initial interventions, defined as in Humpage (1988), are found to have had a larger announcement effect.

3.4 CONCLUSIONS

Publicly available intervention data sufficiently detailed and frequent to carry out reasonable investigations is still lacking. In spite of that, several interesting features of the objectives central banks pursued with their interventions have been uncovered. Longworth (1980) is the first study to go beyond the usual verification of 'leaning against the wind' behaviour. The Bank of Canada is found to have reacted symmetrically across months with a rising and a declining value of the Canadian dollar in terms of the US dollar. Later studies, e.g. Bischofberger (1986), Gärtner (1987) and Honegger (1989), have continued the search for asymmetries in the intervention behaviour and extended it to cover more countries. A very informative specification of an intervention reaction function leaves open the possibility that central banks act differently in case their currency is overvalued as compared to the case in which it is undervalued with respect to PPP. Honegger (1989) finds that the Bank of Japan only 'leaned against the wind' when the yen was overvalued. The Bundesbank appears to have been concerned with countering appreciations of the DM *vis-à-vis* the US dollar only, while the Bank of England only opposed depreciations of sterling. The search for asymmetries in the more recent studies replaces attempts to include deviations from a target level as an explanatory variable in the reaction function in the more dated studies such as Artus (1976), Quirk (1977) and König and Gaab (1982). Asymmetries in 'leaning against the wind' behaviour point to specific objects central banks want to attain, e.g., low inflation and improved competitiveness of domestic industries.

This contrasts with the assumption underlying most target level specifications that central banks want to bring the exchange rates in line with PPP.

In general, no systematic effect of sterilized intervention via the portfolio balance channel is found, implying that interventions do not constitute an independent tool of monetary policy. Data limitations and theoretical and econometric problems have made it impossible to estimate the portfolio balance model and measure the effects of sterilized intervention satisfactorily. Furthermore, the scale of intervention relative to the magnitude of flows in the foreign exchange market and relative to the magnitude of stocks of private foreign assets is insignificant. Therefore, on the basis of casual empiricism the potential for central banks to cause a significant imbalance in investors' portfolios seems negligible.

Only official exchange market operations which create expectations of changes in monetary policy or which embody another sufficient 'news'-content appear to have a chance of affecting the exchange rate significantly. Several attempts, such as Humpage (1988), Eijffinger and Gruijters (1992) and Dominguez (1990), have been made to detect the components of which the announcement effect is made up. In this context the extra-effectiveness of intervention carried out after a certain period of no intervention and coordinated intervention is investigated. The results are rather mixed indicating perhaps that whether or not market participants pay attention to the interventions also depends on the availability of other 'news'. Furthermore, statements of politicians and monetary authorities which accompany the intervention can lend support to or detract from its effectiveness.

NOTES

1. This chapter is based on Almekinders and Eijffinger (1991).
2. Taylor (1982) investigates the profitability of foreign exchange market intervention. Therefore, this study does not fit within the framework of our study.
3. Argy (1982, p. 68) defines gross intervention as the summed absolute values of the monthly volumes of intervention, divided by exports in that year. Net intervention is the same except that the sum of the months takes account of signs.
4. This may cause the number of observations to become too small to be able to present meaningful estimates. These numbers are not reported by Bischofberger.
5. Unlike Bischofberger (1986), Gärtner reports on the number of observations applying to each case.
6. Obstfeld (1988) discusses the importance of central bank intervention relative to monetary and fiscal policy for the determination of exchange rates during the period 1985—88.
7. This method is open to question because survey data do not have to correspond with market expectations. Market participants may be interested in masking their actual expectations. For a survey of the pros and cons of using survey data, see Takagi (1991).
8. It should be noted that Dominguez constructs a dummy variable which is set to unity for the

days on which the Bank of Japan was in the market, according to her information, and zero otherwise for the three-year sample period. Despite these questionable data she draws some tentative conclusions on coordinated interventions by the three central banks.

4. Objectives of Daily Bundesbank and Federal Reserve Intervention in the DM/$ Market — Part I

4.1 INTRODUCTION[1]

This chapter reports on the results of an empirical investigation into the objectives of daily foreign exchange market intervention by the Deutsche Bundesbank and the Federal Reserve System in the US dollar—Deutsche Mark market. This study makes three contributions to understanding and testing the objectives of central bank interventions. Firstly, the investigations reported in this chapter deliberately focus on the short-term objectives of intervention in the dollar—DM exchange market. Secondly, particular attention will be paid to the respective central banks' behaviour towards *ex ante* exchange market volatility. This is done by making use of the insights provided by the recent GARCH literature in financial economics. Thirdly, Tobit analysis is implemented to obtain consistent estimates of the intervention reaction functions in spite of the fact that the central banks did not intervene on the majority of the trading days in the sample.

The previous chapter surveyed earlier empirical studies of central bank intervention reaction functions. These studies are based on monthly or quarterly intervention data. Consequently, they focus on the longer-term objectives of foreign exchange intervention. As a result, they usually ignore or deduct from the short-term strategy of 'countering disorderly market conditions' which results in the smoothing of exchange rate volatility from day to day and even during the day.

The investigations reported in this chapter deliberately focus on the short-term objectives of intervention in the dollar—DM exchange market. Daily intervention data of the Bundesbank and the Federal Reserve are used. The disadvantage of such an approach is the vanishing relation between intervention and the 'fundamentals' which are measured on a monthly or quarterly base. Nevertheless, this approach has a decisive advantage, because it captures better the frequency and pattern of exchange market intervention with respect to 'countering disorderly market conditions' and 'leaning against the wind' over shorter periods. Thereby, it should be noted that the intervention behaviour of central banks is not only reflected in the direction and volume, but also in the timing and technique of intervention. The timing refers to the question whether the exchange market is 'thin' and uncertain or not, while the technique relates to the way in which a central bank implements its intervention, i.e. by domestic and possibly foreign commercial banks or by currency brokers with different announcement effects.

Despite the importance of both timing and technique for intervention behaviour, these elements can not be taken into account by our study and will surely detract from the explanatory power of the intervention reaction functions.[2]

In the empirical investigations reported in this chapter, particular attention will be paid to the respective central banks' behaviour towards anticipated exchange market volatility. Applications of the GARCH model reveal that volatility is predictable in most financial markets (for a survey, see Bollerslev et al. 1992). Shocks to daily exchange rate returns in period t show a considerable persistence onto the conditional volatility in consecutive periods. The conditional variance of daily returns in the US dollar—Deutsche Mark exchange market will be used as a proxy for the *ex ante* exchange rate risk. It is expected that the central banks try to compress the perceived risk by means of direct foreign exchange market operations.

The study concentrates on intervention of both central banks in the *spot* dollar/DM exchange market. Daily observations for the official interventions are used. Focus is on 'active' intervention which takes place *inside* the dollar/DM exchange market. It is well known that foreign exchange market participants are eager to detect any information related to official foreign exchange intervention. Central bankers, in turn, know that their actions are monitored very carefully. Therefore, it seems reasonable to assume that all interventions undertaken inside the dollar/DM exchange market are intended to influence the price formation on the market. 'Passive' intervention which takes place outside the market is left out of consideration.

The data available to this study run from February 1985 through to October 1990. Four periods of at least three months with prolonged intervention in one direction have been selected as relevant subsamples: September 1987—January 1988, June 1988—September 1988, December 1988—June 1989 and August 1989—October 1989. These periods are all after the Louvre Agreement of February 22, 1987. Therefore, the same exchange rate policy regime applies to each, making them comparable in at least one respect.

This chapter is organized into five remaining sections, followed by two appendices. Section 4.2 examines the stated objectives of exchange market intervention by central banks in the G-7 countries in general and by the Bundesbank and Federal Reserve in particular. Section 4.3 presents an update of the empirical results in Eijffinger and Gruijters (1991) for periods of at least three months. The volume of Bundesbank and Federal Reserve intervention is regressed on a constant and the difference between the current exchange rate of the US dollar in terms of Deutsche Marks in the Frankfurt foreign exchange market and a moving average of the exchange rate in previous days. Section 4.4 discusses the relevance of using the information contained in the evolution of the conditional variance of daily returns in the US dollar—Deutsche Mark exchange market as an additional regressor in the short-term reaction function for daily interventions. Furthermore, OLS estimation results for the amended Bundesbank and Federal Reserve intervention reaction functions are presented. Section 4.5 centres on the actual inappropriateness of the simple OLS estimation technique used in Section 4.4. Tobit analysis is implemented to deal with the problem of a large proportion of zero-observations for the dependent variable in the reaction functions. This obtains consistent estimates of the intervention reaction functions. It is found that an increase in the conditional variance in daily exchange rate returns derived from a GARCH model estimated in the paper, led the Bundesbank and the Federal Reserve to increase the volume of intervention, for both dollar sales and purchases on account of their 'leaning against the wind policy. Section 4.6 contains a summary and concluding remarks. Appendix A4.1 introduces the GARCH model for daily exchange rate returns and shows that the stochastic process which generates the DM/$ return changed markedly after the establishment of the Louvre Agreement of February 22, 1987. Appendix A4.2 provides some technical details on Tobit analysis.

4.2 STATED OBJECTIVES OF INTERVENTION

Since the breakdown of the Bretton Woods fixed exchange rate system in the early 1970s, the exchange value of the major currencies in the industrialized world is in principle determined by market forces. However, in the present system of managed floating the exchange rate is not the outcome of supply and demand by private market participants only. The monetary authorities of many countries have frequently tried to influence the relative value of their currency by means of exchange market interventions. In the short term all central banks have a common objective of 'countering disorderly exchange market conditions'. It is part of their commitment to promote exchange stability in accordance with Article I of the Articles of Agreement of the International Monetary Fund as amended effective November 11, 1992 (IMF 1993). As stated by the Working Group on Exchange Market Intervention (Jurgensen 1983) and repeated by Dudler (1988), 'disorderly market conditions' are indicated by a substantial widening of bid-asked spreads, large intraday exchange rate movements, 'thin' or highly uncertain trading, destabilizing impacts of essentially non-economic shocks and self-sustaining exchange rate movements which may gain a momentum of their own. The medium-term objectives relate to resisting large short-term exchange rate movements or 'erratic fluctuations' which exceed a certain size, buying time by the central banks to reassess their policies, and 'leaning against the wind' which has been pursued by some over short periods and by others over longer periods. The long-term objectives vary from resisting exchange rate movements, which are believed to be unjustified with respect to the fundamentals (inflation, money growth, balance of payments accounts, etc.), and attempts to give some leeway to monetary policy by lessening the impact of foreign shocks on domestic monetary conditions, to resisting depreciation because of its inflationary effects and resisting appreciation in order to maintain competitiveness. Other objectives are, for example, attempts to acquire foreign currencies without generating (renewed) downward pressure on the domestic currency.

According to the Working Group on Exchange Market Intervention (Jurgensen 1983) the Bundesbank

> has sought from the onset of floating to counter disorderly market conditions, dampen 'erratic' short-term exchange rate fluctuations and smooth out excessive swings in the DM/US dollar rate over longer periods (p. 13)

whereas Smith and Madigan (1988) state that

> for the period since March 1973 as a whole it is probably correct to say that the United States had no exchange rate objective. (Smith and Madigan 1988, p. 188)

Obviously, for the large US economy currency movements are relatively unimportant in their ultimate repercussions on domestic growth and inflation. Therefore, as its maximum tolerable exchange rate changes are smaller, the Bundesbank will feel the need to intervene earlier than the Fed for given movements of the US dollar/DM rate. On the other hand, the weight assigned to exchange rate stabilization might be larger for the

Federal Reserve after the Louvre Accord. While coordinated interventions are expected to have a larger chance of affecting the development of the exchange rate through their larger announcement effect, the Bundesbank will urge the Fed to do its bit, or the other way around.

4.3 AN EMPIRICAL STUDY OF THE REACTION FUNCTION OF THE BUNDESBANK AND THE FEDERAL RESERVE SYSTEM

4.3.1 The data

An empirical study of the reaction function for daily interventions by the Deutsche Bundesbank and the Federal Reserve System in the spot US dollar—Deutsche Mark exchange market must take account of the development of the dollar—DM exchange rate between successive days (interday), as well as in the course of these days (intraday).[3] In this study the intraday development is approximated by three observations per day in the Frankfurt market:

1. the opening rate at 8.30 hours (Frankfurt time), $SFR_t^{8.30}$;
2. the fixing rate at 13.00 hours (Frankfurt time), $SFR_t^{13.00}$;
3. the closing rate at 16:30 hours (Frankfurt time), $SFR_t^{16.30}$.

Because the opening and closing rates are only available from February 1985, the sample period chosen is from February 1985 until October 1990.[4] Furthermore, the results reported in this chapter are based on data for daily interventions in the US dollar—DM exchange market. Two time series are used.[5] First, US dollar interventions of the Deutsche Bundesbank expressed in Deutsche Marks against the DM/dollar intervention rate of that day (INV_t^{DBB}). Second, DM interventions of the Federal Reserve Bank of New York, acting on behalf of the Federal Reserve System, so far as these operations affect the net foreign position of the Bundesbank (INV_t^{FED}). Federal Reserve interventions affect the net foreign position of the Bundesbank e.g. when the Federal Reserve finances its DM sales by calling on the swap agreement with the Bundesbank or from its DM balances at the Bundesbank, or when the Federal Reserve invests its DM purchases at the Bundesbank.

The sample period (February 1985—October 1990) consists of 1,439 trading days. On the majority of these days no interventions were carried out by the Bundesbank and the Federal Reserve System. Months which comprise less than four interventions are left out of consideration. Four periods of at least three months with prolonged interventions in one direction by either of the central banks have been selected as relevant subsamples. The reason for this will be explained in the next section.

The first period runs from September 1987 (for the Fed: October 1987) to January 1988. It seems that during this period, the G-3 countries were no longer willing to direct monetary policy at stabilizing exchange rates as was agreed upon at the Louvre meeting. Furthermore, the October 1987 stock market crash is likely to have caught exchange market participants off balance, calling for dollar-supporting intervention.

In the first half of 1988, the US dollar recovered gradually from its steep decline in the aftermath of the stock market crash. The dollar's upward movement against the mark strengthened vigorously during the second period considered in this paper, June 1988 through September 1988. It appeared to be possible for the US economy to experience a relatively strong growth without frustrating external adjustment. The announcement of US trade deficits which were much smaller than expected led exchange market participants to anticipate a further appreciation of the dollar.[6] Coordinated central bank interventions in August 1988 carried out to counteract this rise were supported by the Bundesbank's move, on August 25, to raise its discount rate by ½ percentage point leading to a narrowing of the interest differential in favour of the dollar.

The third period runs from December 1988 to March 1989 for the Bundesbank. For the Federal Reserve System it begins in January 1989 and ends in June 1989. Political strains in Germany and Japan on the one hand, and a widening short-term interest differential favouring the US dollar over the Deutsche Mark on the other hand put the value of the dollar under upward pressure. Thereby, the market temporarily overlooked the structural weakness of the US dollar caused by the persistent US 'twin deficit'. The buoyancy of the dollar and thus the perceived need for (US) intervention finally subsided in late June 1989. Indications of a deceleration of economic growth and a lessening of inflationary pressure led to market expectations of an easier US monetary policy stance and lower short-term interest rates.

The fourth period chosen is August 1989—October 1989. During this period, again, the dollar came under upward pressure. The currency was strengthened by lower than expected US trade deficits for June and July released on August 17 and September 15, respectively, and favourable employment and retail sales data lowering the probability, as perceived by market participants, of an easing of US monetary policy. By means of official sales of dollars, in part undertaken after a G-7 meeting on September 23, the Bundesbank and the Fed tried to convince market participants that the G-7 monetary authorities were firmly committed to resisting the dollar's rise and maintaining exchange rate stability.

4.3.2 Estimation results for the intervention reaction function

Quirk (1977) uses monthly data. He distinguishes two types of intervention behaviour. First, intervention on account of a 'leaning against the wind' policy. The reaction function for this case is given by

$$INV_t = a\ (S_t - S_{t-1}) \tag{4.1}$$

Second, intervention consistent with gliding parities calculated as a moving average of previous levels of the exchange rate:

$$INV_t = b\ (S_t - \sum_i a_i\ S_{t-i}),\ \text{with} \sum_i a_i = 1 \tag{4.2}$$

where INV_t is the volume of intervention expressed in the home currency and S_t is the spot exchange rate (home currency price of one unit of foreign currency). The same two specifications can be distinguished when daily data are used. In fact, the latter specification is central to the investigations in Eijffinger and Gruijters (1991). This section presents an update of their study.

The interventions by the Bundesbank (INV_t^{DBB}) and the Federal Reserve System (INV_t^{FED}) in the US dollar—Deutsche Mark exchange market are explained by a constant and the difference between the opening rate of the dollar in DM in the Frankfurt market ($SFR_t^{8.30}$) and the seven-days moving average of the opening rate, fixing rate ($SFR_t^{13.00}$) and closing rate ($SFR_t^{16.30}$) of the dollar.[7] The seven-days moving average of the DM/$ rate in Frankfurt is calculated as follows:

$$SFR_t^{MA} = \frac{1}{21} \sum_{n=1}^{7} (SFR^{8.30} + SFR^{13.00} + SFR^{16.30})_{t-n}$$

The intervention reaction function can be written:

$$INV_t^{DBB/FED} = a_0 + a_1 \left(SFR_t^{8.30} - SFR_t^{MA}\right) + \mu_t \tag{4.3}$$

where μ_t is the residual of the reaction function. The exchange market interventions by the Bundesbank and Federal Reserve are both expressed in billions of Deutsche Marks. The interventions are positive if the central bank buys US dollars in return for Deutsche Marks. The Deutsche Mark/US dollar exchange rate is defined as the spot value of one US dollar expressed in Deutsche Marks at the Frankfurt exchange. The constant in the reaction function (4.3) (a_0) reflects, when significant, a bias of the intervening central bank with respect to the DM/$ rate based on the development of the 'fundamentals', such as the (long-term) capital account, the current account, the inflation rate and the growth rate of the money stock in Germany and the United States. A positive constant represents an autonomous bias of the central bank concerned towards a dollar appreciation *vis-à-vis* the Deutsche Mark in the medium (and long) run.[8] The smoothing or 'leaning against the wind' coefficient (a_1) reflects the reaction of the central bank by exchange market intervention on a deviation of the current exchange rate — i.e. the opening rate on day t in the Frankfurt market — from the average level of the exchange rate during the previous days. As a proxy for the average level of the exchange rate, a moving average of the opening, fixing and closing rates during the previous seven trading days in the Frankfurt market is chosen. During periods of an increasing (decreasing) value of the US dollar in terms of the DM, the difference between the opening rate of the day and the moving average (the bracketed term in equation (4.3)) tends to be positive (negative). Consequently, a positive (negative) value of the coefficient a_1 would imply that the central bank tends to buy (sell) US dollars when the exchange rate of one US dollar in terms of Deutsche Marks is rising (declining). While the Bundesbank and the Federal Reserve are supposed to pursue a policy of 'leaning *against* the wind', the smoothing coefficient is expected to have a negative sign. This means that the central banks try to dampen the volatility of the DM/dollar rate in the short run by exchange market intervention.[9]

The results from estimating equation (4.3) by ordinary least squares (OLS) are reported in Table 4.1. The constant (a_0) is significant in all eight regressions. For the first subsample it has a positive sign consistent with the fact that both central banks only bought US dollars during that period. The opposite case applies to the other three subsamples. The smoothing or 'leaning against the wind' coefficient (a_1) has the expected negative sign except for the fourth subsample. In the case of the Bundesbank, this 'leaning *with* the wind' is statistically significant. Neither a closer inspection of the data nor a broad characterization of the major economic issues during the particular period reveal an explanation for this apparent 'leaning *with* the wind' by both the Bundesbank and the Fed. The announcement of a smaller than expected US trade deficit in August and September 1989 pushed the (value of the) dollar above DM2, inducing dollar sales by the central banks.

The values of the Durbin—Watson test statistic given in Table 4.1 clearly indicate that first-order autocorrelation in the residuals of equation (4.3) is a problem. Although the lower bound of the critical value for each regression varies with the number of observations in the subsample, it can easily be checked that only for the fourth subsample in the case of the Federal Reserve is the null hypothesis of uncorrelated errors not

Table 4.1 OLS estimation results for the reaction function in (4.3)

$$INV_t^{DBB/FED} = a_0 + a_1 \left(SFR_t^{8.30} - SFR_t^{MA}\right)$$

Period	a_0	a_1	$\bar{R}^2$	DW	Obs.
Deutsche Bundesbank					
1987(9)—1988(1)	0.035	—2.957	0.241	1.41	105
	(3.18)	(—5.83)			
1988(6)—1988(9)	—0.138	—4.490	0.086	1.59	86
	(—4.87)	(—3.00)			
1988(12)—1989(3)	—0.029	—2.695	0.152	1.59	84
	(—2.64)	(—3.98)			
1989(8)—1989(10)	—0.027	0.939	0.068	1.33	66
	(—2.77)	(2.40)			
Federal Reserve System					
1987(10)—1988(1)	0.036	—2.044	0.117	1.35	83
	(2.54)	(—3.45)			
1988(6)—1988(9)	—0.080	—4.444	0.137	1.23	86
	(—3.63)	(—3.80)			
1989(1)—1989(6)	—0.102	—4.344	0.150	1.67	124
	(—5.25)	(—4.76)			
1989(8)—1989(10)	—0.075	0.226	—0.013	1.86	66
	(—4.71)	(0.38)			

Notes:
t-statistics are in parentheses.
$\bar{R}^2$ is the squared multiple correlation coefficient adjusted for degrees of freedom.
DW is the Durbin—Watson statistic for first-order autocorrelation.
Obs. gives the number of observations for each period.

rejected. In the following sections a different specification of the reaction function and a more appropriate estimation technique will be used to describe the intervention behaviour more satisfactorily.

4.4 THE REACTION TOWARDS ANTICIPATED EXCHANGE RATE VOLATILITY

In the previous section the reaction of the central banks to a divergence of the actual from the desired exchange rate was estimated. The desired level of the exchange rate was proxied by the seven-days moving average of the exchange rate. Therefore, the central banks' reaction patterns were assumed to be guided by realized values of the exchange rate.

The evolution over time of the variance or standard deviation of exchange rate changes and other statistical properties derived from the behaviour of exchange rates have recently become an intensively studied subject. Several recent studies have applied Engle's (1982) autoregressive conditionally heteroskedastic (ARCH) model and Bollerslev's (1986) extension to a generalized ARCH (GARCH) model to describe time-varying variances in exchange rates. The purport of the extensive GARCH literature is that volatility in daily returns is predictable in most financial markets. In several applications it has been shown that there is a long-term persistence in the effects of shocks in period t onto the conditional variance of exchange rates in period $t+s$ for large s. On the assumption that central banks are aware of this regularity, the forward-looking nature of foreign exchange market operations can be tested by including a conditional variance term in the reaction function.

The investigations in this chapter are concerned with exchange rate risk associated with *interday* movements of the exchange rate only.[10] The conditional variance of daily returns in the US dollar—Deutsche Mark exchange market will be used as a proxy for the anticipated exchange rate volatility. An increase in the conditional variance is not only likely to cause 'disorderly market conditions' on the foreign exchange market, but also it may have an adverse effect on the volume of international trade. Until recently, the effect of exchange rate volatility on the volume of international trade remained an unresolved issue. Theory is indeterminate on this issue.[11] Furthermore, Bini Smaghi (1991) explains why it is so difficult to find any empirical relationship. Using sufficiently disaggregated data on trade flows, he finds that, for the period 1976—84, the standard deviation of weekly rates of change of the intra-EMS effective exchange rate during a quarter had a significantly negative effect on the volume of exports of the countries considered (Germany, France and Italy) in the same quarter.

In the previous section four periods were selected of at least three months with prolonged interventions in one direction by one of the central banks. The reason for this is as follows. The variance of a time series is positive by definition. It seems reasonable to expect a central bank, *ceteris paribus*, either to buy *or* sell more US dollars in the case of an increase in the conditional variance of the return series depending on the initial direction of intervention. Therefore, the expected sign of the coefficient for the conditional variance term in the intervention reaction function is positive (negative) when the period is characterized by purchases (sales) of US dollars by the central banks.

The periods selected all occur after the establishment of the Louvre Agreement of February 22, 1987. Estimation results presented in Appendix A4.1 point to a marked change in the stochastic process generating the DM—US dollar return series as of that date. Furthermore, these estimation results suggest that the process remained relatively stable at least until October 1989. Therefore, the sample period used to estimate the GARCH model runs from February 23, 1987 through to October 31, 1989 totalling 677 observations. The model can be written:

$$\begin{aligned} &100\ \Delta \log SFR_t^{16.30} = b_0 + \epsilon_t \\ &\epsilon_t \mid \Omega_{t-1} \sim N(0, h_t) \\ &h_t = \pi + \alpha\, \epsilon_{t-1}^2 + \beta\, h_{t-1} \end{aligned} \tag{4.4}$$

with $\pi, \alpha, \beta > 0$, $\alpha + \beta < 1$. $SFR_t^{16.30}$ is the closing rate of one US dollar in terms of DM at the Frankfurt foreign exchange market. The first line of the GARCH model in equation (4.4) represents the mean equation of the model. The dependent variable is the percentage change of the closing rate of the US dollar. ϵ_t is the residual of the mean equation. The second line of the model states that this residual has a conditional normal distribution with mean zero and variance h_t. Ω_{t-1} indicates the information available to exchange market participants as of time t—1. The third line of the model defines the variance equation (h_t).

The maximum likelihood estimation results for the GARCH model in equation (4.4) are shown in Table 4.2. The constant in the mean equation (b_0) does not differ significantly from zero. Obviously, the DM/dollar rate did not increase uniformly across the sample. The high standard deviation of the daily returns in the dollar—DM market renders an insignificant constant in the mean equation. The other coefficients of the GARCH model in (4.4) are highly significant. The value of the likelihood ratio (LR) test statistic in the last column of Table 4.2 indicates that the null hypothesis $H_0 : \alpha = \beta = 0$ can be soundly rejected. This implies that the random-walk model with a GARCH error term fits the data better than the random-walk model with a Gaussian error term. Although the residuals still exhibit some excess kurtosis, it

Table 4.2 Maximum likelihood estimates for the parameters of the GARCH model in equation (4.4)

b_0	π	α	β	logL	Q(12)	$Q^2(12)$	m_3	m_4	LR(2)
0.015	0.021	0.073	0.87	−649.34	10.29	20.63	0.04	4.29	35.68
(0.65)	(2.77)	(4.47)	(31.15)						

Notes: t-statistics are in parentheses.
m_3 and m_4 give the sample skewness and kurtosis for the residuals, respectively.
Q(12) and $Q^2(12)$ refer to the Ljung—Box portmanteau test for up to 12th order serial correlation in the levels and the squares of the residuals, respectively. The critical value for a 5%-level test is 21.0.
LR(2) gives the value of the test statistic for the likelihood ratio test under the null hypothesis that the variance is conditional homoskedastic $H_0 : \alpha = \beta = 0$. As the alternative hypothesis is $H_1 : \alpha \geq 0, \beta \geq 0$, the LR-statistic does not have a χ^2-distribution with two degrees of freedom. The tabulated critical value for a 5%-level test is 5.135 (Kodde and Palm 1986).

can be argued that the conditional normal specification in (4.4) captures the stylized facts of the DM/dollar exchange rate fairly well. The estimation results depicted in Table 4.2 are used to generate a time series for the conditional variance of the daily DM/dollar return. The unconditional or average variance of the return series for the sample considered in Table 4.2, $\sigma^2 = \pi / (1 - \alpha - \beta) = 0.396$, is used as a starting value.[12] The path of the conditional variance (h_t) for the period from September 1987 to July 1988 is depicted in Figure 4.1. An upturn in the conditional variance during the first period of prolonged (dollar-supporting) intervention stands out. A major strengthening of the US dollar *vis-à-vis* the DM marks the beginning of the second subsample. The course of the DM/dollar rate, its seven-days moving average and the conditional variance of daily DM/$ returns for the period December 1988 to October 1989 is shown in Figure 4.2. During the third subsample the value of the US dollar *vis-à-vis* the Deutsche Mark increased rather sharply. The conditional variance of daily returns experienced major gyrations from May 1989 onwards.

OLS estimation results for the intervention reaction function for the Bundesbank and the Federal Reserve System which includes the conditional variance of the daily return in the US dollar—Deutsche Mark market as an additional explanatory variable are reported in Table 4.3. When comparing these results with those in Table 4.1, it is obvious that the conditional variance draws explanatory power away from the constant

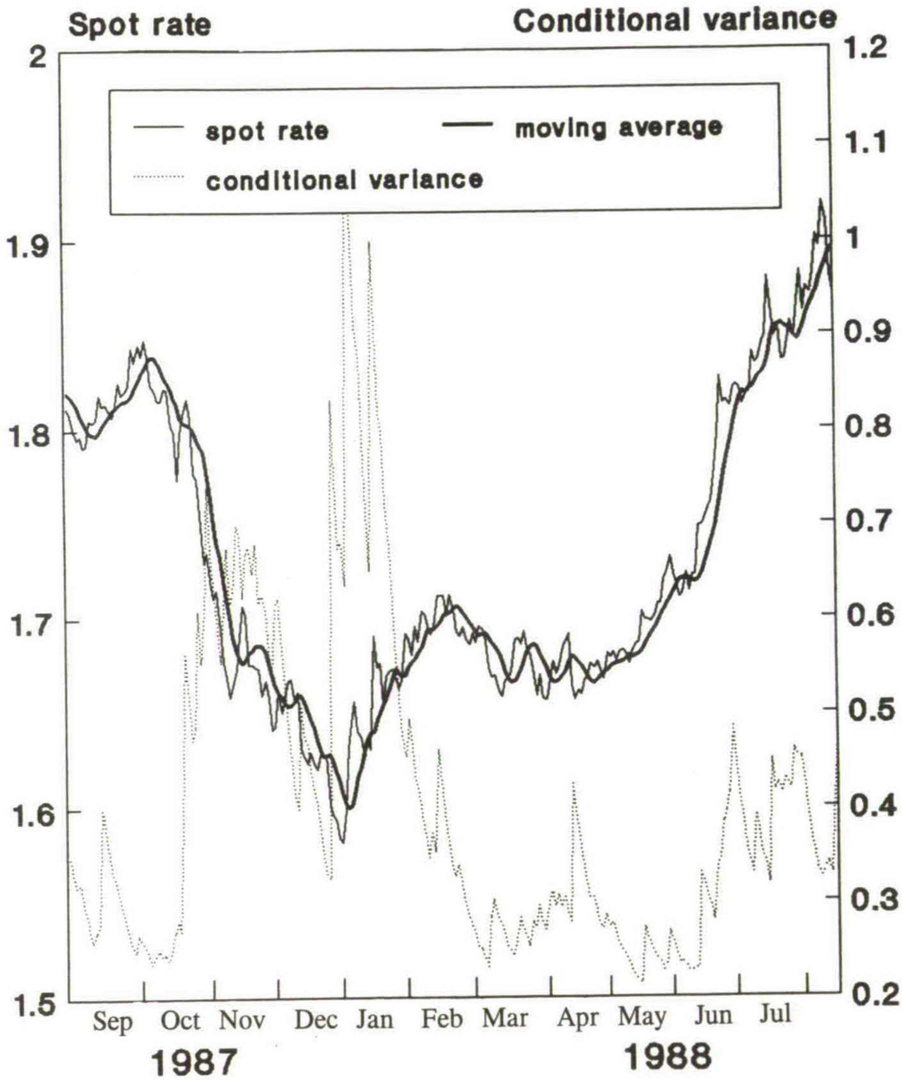

Figure 4.1 *The course of the level of the DM/$ rate and the conditional variance of daily DM/$ returns: September 1987—July 1988.*

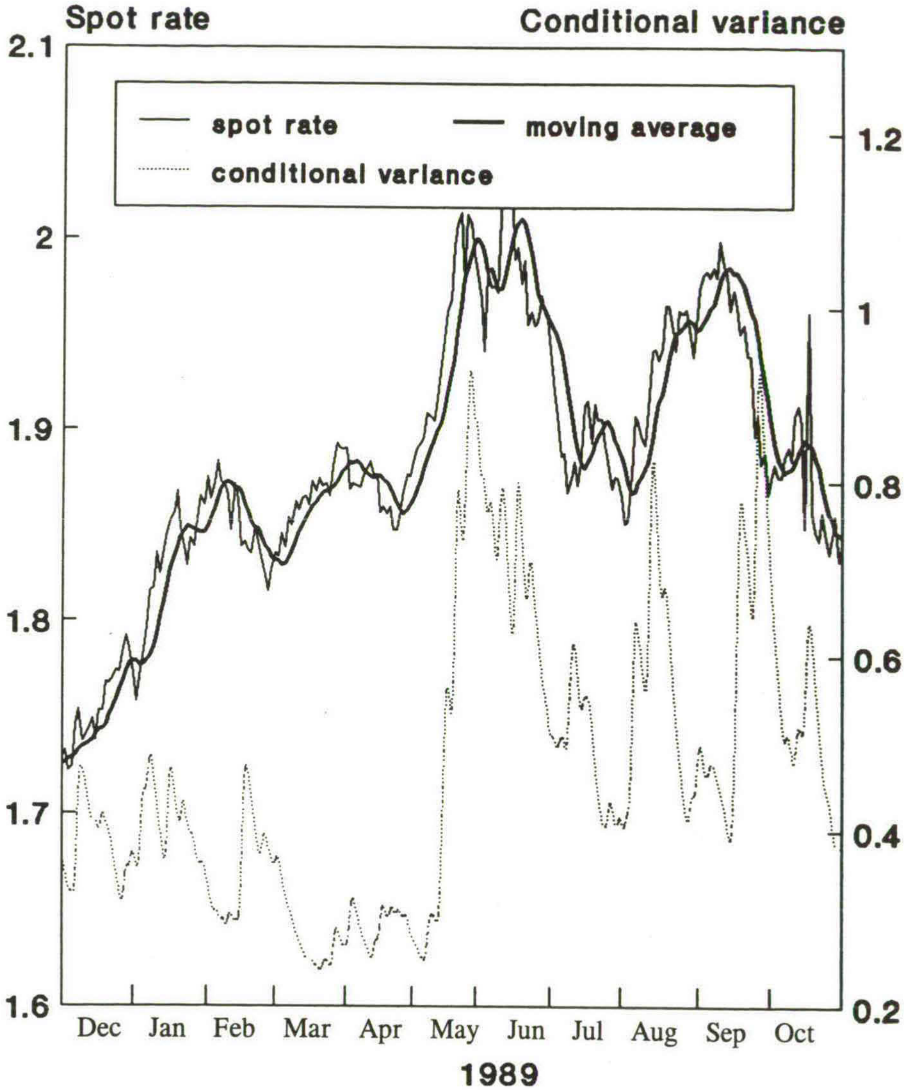

Figure 4.2 *The course of the level of the DM/$ rate and the conditional variance of daily DM/$ returns: December 1988—October 1989.*

Table 4.3 OLS estimation results for the reaction function which includes the conditional variance of the daily return in the DM/$ market as an additional explanatory variable

$$INV_t^{DBB/FED} = c_0 + c_1 \left(SFR_t^{8.30} - SFR_t^{MA} \right) + c_2 \, h_t$$

OLS	c_0	c_1	c_2	$\bar{R}^2$	DW	Obs.
Deutsche Bundesbank						
87(9)—88(1)	−0.034	−3.156	0.134	0.284	1.56	105
	(−1.21)	(−6.34)	(2.68)			
88(6)—88(9)	0.105	−5.514	−0.588	0.151	1.75	86
	(1.13)	(−3.69)	(−2.72)			
88(12)—89(3)	0.047	−2.646	−0.213	0.165	1.63	84
	(0.92)	(−3.94)	(−1.50)			
89(8)—89(10)	0.130	0.723	−0.285	0.298	1.57	66
	(3.75)	(2.26)	(−4.71)			
Federal Reserve System						
87(10)—88(1)	−0.076	−2.573	0.192	0.192	1.56	83
	(−1.87)	(−4.32)	(2.91)			
88(6)—88(9)	0.226	−5.733	−0.740	0.313	1.38	86
	(3.35)	(−5.32)	(−4.75)			
89(1)—89(6)	−0.012	−4.423	−0.207	0.172	1.77	124
	(−0.26)	(−4.91)	(−2.08)			
89(8)—89(10)	0.080	0.084	−0.280	0.068	2.12	66
	(1.29)	(0.15)	(−2.57)			

Notes: See Table 4.1.

(c_0). The smoothing or 'leaning against the wind' coefficient (c_1) remains of equal magnitude. Furthermore, the overall explanatory power of the reaction function, as measured by the squared multiple correlation coefficient adjusted for degrees of freedom, is higher and the problem of first-order autocorrelation in the residuals seems to have become less severe. Most importantly, the conditional variance coefficient has a value which is significantly different from zero with the expected sign in all cases. It is positive in the first subsample when both central banks only bought US dollars and negative in the three remaining subsamples during which the central banks sold US dollars.

A straightforward interpretation of the estimated coefficients in the Bundesbank reaction function for the sample period September 1987—January 1988 could be the following. A one pfennig decline of the actual level of the exchange rate of the US dollar below the desired level led the Bundesbank to buy DM 31.56 million worth of US dollars on average. Furthermore, an increase in the conditional variance by 10 points, say from 0.30 to 0.40, caused by a larger than average percentage change in the DM/$ exchange rate during the previous day, *ceteris paribus* induced the Bundesbank to buy an additional DM 13.4 million worth of US dollars. However, the simple OLS estimation technique in fact does not yield consistent estimates for the coefficients in the reaction functions when using a data set in which large proportions of the observations for the dependent variable are at a limiting value, in this case zero. In economic terms, this implies that a correction is required for the possibility that the one pfennig decline in the actual level of the exchange rate of the US dollar below the desired level or the increase in the conditional variance by 10 points actually were insufficient to lift the volume of intervention above zero. Tobit analysis is the appropriate method to deal with this problem. It is implemented in the next section.

4.5 THE INTERVENTION REACTION FUNCTION ESTIMATED AS A TOBIT MODEL

The OLS estimation technique implemented in Sections 4.3 and 4.4 assumes that the residuals of the reaction functions (μ_t) are independent of the explanatory variables. However, this assumption does not hold when large proportions of the observations for the dependent variable in the reaction function are zero, as is the case in the four subsamples selected above. A possible explanation for the zero interventions is that the central bank does not carry out foreign exchange market operations intended to alter the development of the exchange rate until the perceived necessity to enter the market exceeds a certain level. Neither this necessity nor 'negative' interventions, which correspond to various levels of necessity below the threshold level, can be observed.[13] A reaction function for necessary intervention can be written

$$INV_t^* = d_0 + d_1 \left(SFR_t^{8.30} - SFR_t^{MA} \right) + d_2\, h_t + \mu_t^* \tag{4.5}$$

where INV_t^* is the necessary amount of intervention of the Bundesbank or the Federal Reserve and the residual μ_t^* is assumed to be an identically and independently distributed random variable with mean zero and variance σ^2. The coefficients in Table 4.3 are biased estimators of the coefficient d_0, d_1 and d_2 in equation (4.5). Therefore, μ_t is not identically distributed with mean zero and variance σ^2. The relationship between observed and necessary intervention applying to both buying and selling of foreign exchange is

$$\begin{aligned} INV_t &= INV_t^* \qquad \text{if } INV_t^* > 0 \\ &= 0 \qquad\qquad \text{if } INV_t^* \leq 0 \end{aligned} \tag{4.6}$$

In Tobit analysis, named after Tobin (1958) who pioneered this type of analysis, the parameters in (4.5) are estimated consistently applying maximum likelihood procedures. Appendix A4.2 provides some technical details on Tobit analysis. Table 4.4 reports the Tobit regression results for equation (4.5). In a qualitative sense these do not differ very much from the OLS results reported in Table 4.3. The puzzling 'leaning *with* the wind' coefficient in the fourth subsample for the Bundesbank is no longer significant.

The Tobit regression coefficients overstate the actual effect of unit changes in the explanatory variables on the volume of intervention. A correction is required for the possibility that, for instance, an increase in the divergence of the actual spot rate from the seven-days moving average of the exchange rate does not lead to nonzero interventions. Therefore, the coefficients in Table 4.4 have to be multiplied by the expected probability that the volume of intervention is larger (in the first subsample for both central banks) or smaller (in the other subsamples) than zero. This probability can be derived from the Tobit regression equation with the independent variables set equal to their mean values. The value for each regression is given in Table 4.4. These probabilities *grosso modo* correspond with the (order of the) actual proportions of intervention days in each subsample. At first sight, the expected probability in the second subsample for the Bundesbank, 0.6421, seems

Table 4.4 Tobit regression result for the reaction function in (4.5)

$$INV_t^* = d_0 + d_1 \left(SFR_t^{8.30} - SFR_t^{MA}\right) + d_2\, h_t$$

Period	d_0	d_1	d_2	LogL	Prob.	LR(2)	Obs
Deutsche Bundesbank							
87(9)—88(1)	—0.448	—9.998	0.384	—216.02	0.1425	41.65	105
	(—3.79)	(—5.31)	(2.16)				
88(6)—88(9)	0.327	—7.074	—0.911	—429.50	0.641	15.50	86
	(2.45)	(—3.40)	(—3.06)				
88(12)—89(3)	0.252	—9.140	—0.291	—223.08	0.2530	28.89	84
	(2.03)	(—4.34)	(—0.87)				
89(8)—89(10)	0.522	0.824	—0.704	—122.72	0.0754	15.00	66
	(3.78)	(0.86)	(—3.47)				
Federal Reserve System							
87(10)—88(1)	—0.877	—10.245	0.869	—148.07	0.0821	22.54	83
	(—3.41)	(—3.74)	(2.62)				
88(6)—88(9)	1.037	—14.971	—1.786	—214.88	0.1925	29.50	86
	(4.25)	(—4.35)	(—3.78)				
89(1)—89(6)	0.403	—9.510	—0.493	—381.74	0.2703	23.00	124
	(3.23)	(—4.34)	(—2.15)				
89(8)—89(10)	0.473	—0.255	—0.673	—184.14	0.2272	5.68	66
	(2.61)	(—0.17)	(—2.33)				

Notes:
See Table 4.1.
Prob. gives the expected probability of an intervention volume larger (in the first subsample for both central bank) or smaller (in the other subsamples) than zero.
LR(2) gives the value of the test statistic for the likelihood ratio test that the explanatory variables, other than the constant, have no impact on the volume of intervention. The critical value for a 5%-level test for H_0: $d_1 = d_2 = 0$ is 5.99.

to be an outlier. However, the Bundesbank intervened on 57 of the 86 trading days from June 1988 through September 1988, the calculated proportion of intervention days being 57/86=0.663. In the other cases, the calculated probabilities underestimate the proportion of days with nonzero interventions.

4.6 CONCLUSIONS

The estimation results presented in this study indicate that both the Bundesbank and the Federal Reserve System conducted their official foreign exchange operations consistently. Daily intervention data were available. This made it possible to test whether intervention by the Bundesbank and the Federal Reserve was guided by their commitment to promote a stable exchange rate system and, thus, whether they tried to counter 'disorderly market conditions' from day to day. A 'leaning against the wind' policy appears to have prevailed across four post-Louvre subsamples of at least three months. In one of the subsamples, a significant 'leaning *with* the wind' coefficient was found initially. However, it turned insignificant when Tobit analysis, the appropriate estimation technique given the large proportion of zero-observations for the volume of intervention, was implemented.

The 'leaning against the wind' coefficient relates the volume of intervention on day t to the difference between the opening rate of the US dollar in Deutsche Marks at the Frankfurt foreign exchange market and a seven-days moving average of the opening, fixing and closing rate. It should be noticed that the moving average refers to realized values of the exchange rate. An attempt has been made to reveal a glimpse of the forward-looking nature of foreign exchange market operations by including a conditional variance term in the intervention reaction function. In fact, this study investigates whether the central banks take into account the well-established empirical regularity that daily returns on foreign exchange markets show clusters of outliers, i.e. that exchange rate volatility is predictable to some extent. Estimation results presented in this chapter confirm recent evidence that the GARCH model gives a good description of the statistical properties of daily exchange rate returns on the US dollar—Deutsche Mark market. With the conditional variance modelled as a weighted average of the variance in past days with geometrically declining weights, the GARCH model can capture the stylized fact of clusters of large DM/dollar returns. The time series for the conditional variance is derived from the estimated GARCH model. The estimated coefficient for the conditional variance term in the intervention reaction functions has the expected sign in all cases. It is found that an increase in the conditional variance led the central banks to increase the volume of intervention, in the case of both dollar sales and purchases on account of their 'leaning against the wind' policy. In other words, both central banks take full account of exchange market uncertainty with respect to their intervention policy.

There seem to be some good reasons for this accentuation of the central banks' presence on the foreign exchange market. An increased conditional variance of daily exchange rate returns is apt to cause 'disorderly conditions' on the foreign exchange market and, if persistent, has adverse effects on the volume of international trade as well (Bini Smaghi (1991)).

APPENDIX A4.1 GARCH MODELS AND EXCHANGE RATE POLICY[14]

A4.1.1 Introduction

The aim of this appendix is to explain some of the statistical properties derived from the behaviour of the daily exchange rate of the US dollar in terms of Deutsche Marks for the period March 1985 to September 1988. Furthermore, an attempt will be made to identify changes in the statistical properties corresponding to shifts in the exchange rate policy regime.

The Plaza Agreement of September 22, 1985 and the Louvre Agreement of February 22, 1987 entailed major changes in the coordination of exchange rate policies and the frequency and volume of official exchange market operations among the main industrialized countries. The Telephone Agreement of December 22, 1987 is seen by most observers as a confirmation of the Louvre Agreement. The effect of these shifts in G-7 exchange rate policy regimes on the stochastic process that generated the DM/$ rate will be examined. In particular, it will be investigated whether the monetary authorities' determination to bring the level of the DM/$ rate in line with fundamentals was accompanied by a decline in the (un)conditional variance of this exchange rate.

This appendix is organized into three remaining sections. Estimation results for a random-walk model with drift and a GARCH error term for the DM/$ exchange rate are reported in Section A4.1.2. Furthermore, some tests are carried out to determine whether this model provides a good description of the data. Section A4.1.3 introduces dummy variables to account for the different exchange rate policy regimes. Section A4.1.4 provides a summary of the empirical findings and concluding remarks.

A4.1.2 Random-walk model with drift and a GARCH error term

The exchange rate under consideration is the midpoint between closing bid and ask prices at 16.30 hours in Frankfurt time of the Deutsche Mark *vis-à-vis* the US dollar. In the main text of this chapter it is denoted by $SFR_t^{16.30}$.[15] The sample period chosen is from March 1, 1985 up to September 30, 1988. During this sample period, which totals 895 observations, the DM/$ rate initially showed a steady decline brought about, *inter alia*, by the establishment of the Plaza Agreement of September 22, 1985. The Louvre Agreement of February 22, 1987 marked the beginning of a period of relative stability in the nominal DM/$ exchange rate, lasting until the end of the sample.

To be able to analyse the (un)conditional variance of the time series for $SFR_t^{16.30}$, an adequate representation for the conditional mean has to be found. In line with what is commonly found in the literature on short-run exchange rate movements, the hypothesis that the autoregression of $\log S_t^U$ has a unit root could not be rejected in an 'augmented Dickey—Fuller test' (see, e.g. Meese and Singleton, 1982). A stationary random variable is obtained by taking the first difference of the time series. As is well known by now, the simple random-walk model with drift and Gaussian errors is not able to account for the stylized facts of heteroskedasticity in, and fat-tailedness of, the distribution of exchange rate returns (see, e.g. Baillie and Bollerslev (1989) and the literature cited there). Several recent studies have applied Engle's (1982) autoregressive conditionally heteroskedastic (ARCH) model and Bollerslev's (1986) extension to a generalized ARCH (GARCH) model to describe time-varying variances in exchange rates.

An ARCH (q) model for daily exchange rate returns can be written:

$$100\,(\log SFR_t^{16.30} - \log SFR_{t-1}^{16.30}) = b_0 + \epsilon_t \qquad \text{(A4.1a)}$$

$$\epsilon_t \mid \Omega_{t-1} \sim N\,(0,\ h_t) \qquad \text{(A4.1b)}$$

$$h_t = \pi + \sum_{j=1}^{q} \alpha_j\, \epsilon_{t-j}^2 \qquad \text{(A4.1c)}$$

In the GARCH (p,q) model the expression for the conditional variance in (A4.1c) can be written:

$$h_t = \pi + \sum_{j=1}^{q} \alpha_j\, \epsilon_{t-j}^2 + \sum_{j=1}^{p} \beta_j\, h_{t-j} \qquad \text{(A4.1c)'}$$

where ϵ_t is the residual of the mean equation (A4.1a). In essence, the conditional variance equation is set up as an ARMA process. Adding ϵ_t^2 to both sides of (A4.1c)' and some rearranging gives:

$$\epsilon_t^2 = \pi + \sum_{j=1}^{m} (\alpha_j + \beta_j)\, \epsilon_{t-j}^2 - \sum_{j=1}^{p} \beta_j\, \tau_{t-j} + \tau_t \qquad \text{(A4.2)}$$

with $\tau_t = \epsilon_t^2 - h_t$, $m = \max\,(p,q)$ and τ_t is serially uncorrelated. The orders of p and m in equation (A4.2) can be determined using standard time-series techniques. A test based on the portmanteau statistic and the results of overfitting the specified model indicated that the GARCH model with $q=p=1$ represents the data-generating process adequately. Therefore the model on which attention is focused can be written:

$$100\ (\log SFR_t^{16.30} - \log SFR_{t-1}^{16.30}) = b_0 + \epsilon_t \tag{A4.3a}$$

$$\epsilon_t \mid \Omega_{t-1} \sim N\ (0,\ h_t) \tag{A4.3b}$$

$$h_t = \pi + \alpha\ \epsilon_{t-1}^2 + \beta\ h_{t-1} \tag{A4.3c}$$

The conditional variance equation in (A4.3c) can be rewritten into

$$h_t = \sigma^2 + \alpha \sum_{i=0}^{\infty} \beta^i\ (\epsilon_{t-i-1}^2 - \sigma^2) \tag{A4.4}$$

with $\sigma^2 = \pi/(1-\alpha-\beta)$. An outstanding feature of equation (A4.4) is that the conditional variance (h_t) is higher than the unconditional variance (σ^2) when large forecasting errors occurred recently. Therefore, it is not surprising that this specification of the variance equation is generally found to be able to account for the clustering of outliers in exchange rate returns seen in practice.

Table A4.1 Maximum likelihood estimates for the parameters in (A4.3)

b_0	π	α	β	logL	LR(2)
–0.041	0.019	0.106	0.868	–993.15	96.66
(–1.82)	(2.89)	(6.48)	(39.45)		

m_3 = –0.09 m_4 = 4.76 Q(12) = 15.71 $Q^2(12)$ = 18.79

Notes: See Table 4.2

The estimated coefficients for the GARCH model in (A4.3), shown in Table A4.1, are highly significant with one exception. The US dollar—Deutsche Mark exchange rate did not decline uniformly across the sample. As a result, the coefficient in the mean (b_0) is significant at a 10 per cent level only. The value of the likelihood ratio (LR) test statistic in the last column of Table A4.1 indicates that the null hypothesis $H_0 : \alpha = \beta = 0$ can be soundly rejected. This indicates that the random-walk model with a GARCH error term fits the data better than the Gaussian random walk. Under the assumptions of normality, the measure of kurtosis has the asymptotic distribution of $m_4 \sim N(0,\ 24/T)$. The residuals still exhibit some excess kurtosis albeit less than in the case of the simple random-walk model with m_4 = 6.40. Modelling the

GARCH process as a conditional t-distribution as was done by Baillie and Bollerslev (1989), probably would have accounted better for the leptokurtosis present in the unconditional distribution of exchange rate returns. However, the conditional normal specification in (A4.3) captures the stylized facts of the US dollar/DM exchange rate data fairly well. Thereby, a good starting point for the analysis of the effect of changes in the exchange rate policy is created.

A4.1.3 Exchange rate policy and the conditional variance of the daily DM/$ rate

In Section A4.1.2, a stationary random variable has been created by taking the first difference of the time series of the daily DM/$ rate. The unconditional mean and variance of such a variable are constant over time. The variance of the daily returns in the DM/$ market can be computed directly by taking the average of squared deviations from the mean of the series: $\sigma^2 = 0.60$. It can also be calculated from the estimation results for the GARCH model in Table A4.1 as explained above: $\hat{\sigma}^2 = 0.72$. The unconditional variance of the DM/$ returns thus calculated is in fact the average variance for the three-and-a-half-year sample period. This section investigates whether a pattern in the unconditional variance can be identified consistent with the increased efforts by the monetary authorities of the G-7 countries to coordinate their exchange rate policies following the establishment of the Plaza Agreement in the first instance and the Louvre Agreement later on. This issue is of interest because the higher the variance of daily exchange rate changes, the harder it is to predict future values of the rate, i.e. the higher is the uncertainty facing people involved in international trade and investment.

To detect the effect of exchange rate policy regime shifts dummy variables will be included in the random-walk model with GARCH errors estimated in Section A4.2. As will become clear, the relationship between the conditional and the unconditional variance in equation (A4.4) forms the basis for interpreting the estimation results. Therefore, allowance has to be made that the effect of the inclusion of dummy variables in the model can be put back into this crucial relationship. A dummy variable D_t, with value 1 on the days in the first half of the sample and 0 thereafter, is included as follows:

$$h_t = \sigma^2 + \delta_1 D_t + \alpha \sum_{i=0}^{\infty} \beta^i (\epsilon^2_{t-i-1} - \sigma^2 - \delta_1 D_t) \tag{A4.5}$$

which, after some rearranging, can be written as

$$h_t = \sigma^2 (1-\alpha-\beta) + \delta_1 D_t - \delta_1 (\alpha+\beta) D_{t-1} + \alpha \epsilon_{t-1}^2 + \beta h_{t-1} \quad \text{(A4.6)}$$

or, more comprehensively

$$h_t = \pi_0 + \pi_1 D_t + \pi_2 D_{t-1} + \alpha \epsilon_{t-1}^2 + \beta h_{t-1} \quad \text{(A4.7)}$$

The unconditional variance of daily DM/\$ returns during the second half of the sample period, with $D_t = D_{t-1} = 0$, is $\sigma_2^2 = \pi_0 / (1 - \alpha - \beta)$. The unconditional variance during the first half of the sample, σ_1^2, can only be calculated from (A4.7) when it is assumed that $D_t = D_{t-1} = 1$ which seems to be only a minor restriction. In that case the formula runs as follows: $\sigma_1^2 = (\pi_0 + \pi_1 + \pi_2) / (1 - \alpha - \beta)$.

While the one-period lagging of a dummy variable does seem to make much economic sense, estimation results not shown here indicate that the inclusion of the lagged dummy variable does not alter the conclusions. To get a comprehensive picture of the evolution of the unconditional variance across exchange rate policy regimes three dummy variables are included in the model. They are defined as follows:

DPL = 1 on the days between the Plaza Agreement of September 22, 1985 and the Louvre Agreement of February 22, 1987.
0 otherwise.

*DAL*1 = 1 on the days between the Louvre Agreement of February 22, 1987 and the Telephone Agreement of December 22, 1987.
0 otherwise.

DAL2 = 1 on the days between the Telephone Agreement and September 30, 1988 (the end of the sample period).
0 otherwise.

After incorporating these dummy variables, the model looks as follows:

$$100 (\log SFR_t^{16.30} - \log SFR_{t-1}^{16.30}) = b_0 + b_1 DAL1 + b_2 DAL2 + \epsilon_t$$

$$\epsilon_t \mid \Omega_{t-1} \sim N(0, h_t) \quad \text{(A4.8)}$$

$$h_t = \pi_0 + \pi_1 DPL + \pi_2 DAL1 + \pi_3 DAL2 + \alpha \epsilon_{t-1}^2 + \beta h_{t-1}$$

The variable *DPL* is omitted from the mean equation in (A4.8) because it lacks significance. Therefore, it can be concluded that the 'drift' in the random walk is fairly constant from the beginning of the sample through to the establishment of the Louvre Agreement.

Maximum likelihood estimates for the parameters in (A4.8) are depicted in Table A4.2. The unconditional variances of the returns in the DM/$ market during different subperiods, which together constitute the entire sample, calculated from these estimation results are given in the first column of Table A4.3. An indication of the goodness-of-fit of the model can be obtained by comparing them to the values in the second column which give the average actual variance of the returns during each period. Both series in Table A4.3 show a tendency of a declining unconditional variance over the sample consistent with the enhanced international coordination of exchange rate policies from 1985 onwards. The question arises whether this insight is confirmed in statistical tests. The value of the likelihood ratio (LR) test statistic in Table A4.2 gives rise to the rejection of the null hypothesis H_0: $\pi_1=\pi_2=\pi_3=0$, i.e. the hypothesis that the unconditional variance of daily returns in the DM/$ market is constant across the sample. The value of the LR test statistic, 14.3, is even larger than the critical value at a significance level of 0.5 per cent ($\chi^2_{(0.005,\ 3)}$ = 12.8). Given this result and given the inability to reject the hypothesis that π_2 equals π_3, the null hypothesis H_0: $\pi_1=\pi_2=\pi_3$ can be read as the hypothesis that *only* the Plaza Agreement had a

Table A4.2 Maximum likelihood estimates for the parameters in (A4.8)

b_0	b_1	b_2	π_0	π_1	π_2	π_3	α	β	logL
−0.127	0.102	0.201	0.106	−0.066	−0.079	−0.081	0.089	0.836	−977.624
(−3.68)	(1.99)	(4.04)	(3.61)	(−3.08)	(−3.32)	(−3.44)	(4.78)	(27.42)	

m_3 = −0.08 m_4 = 4.68 Q(12) = 12.69 $Q^2(12)$ = 11.78

LR(1) for H_0: $\pi_2=\pi_3$	0.30
LR(2) for H_0: $\pi_1=\pi_2=\pi_3$	2.95
LR(3) for H_0: $\pi_1=\pi_2=\pi_3=0$	14.30
LR(5) for H_0: $b_1=b_2=\pi_1=\pi_2=\pi_3=0$	31.05

Notes: See Table 4.2.

LR(J) gives the value of the test statistic for the likelihood ratio test of the null hypothesis indicated, where J indicates the degrees of freedom. The critical values for a 5%-level test with J=1, J=2, J=3 and J=5 are 3.84, 5.99, 7.81 and 11.07, respectively.

Table A4.3 *Unconditional variance of daily DM/$ returns during different periods*

	From the model	From the data
Before Plaza	1.41	0.99
Between Plaza and Louvre	0.53	0.70
Between Louvre and Telephone Agreement	0.36	0.36
After the Telephone Agreement	0.33	0.39

significant impact on the stochastic process that generated the DM/$ rate. It can be rejected at a 25 per cent significance level only (since $2.95 > \chi^2_{(0.25,\,2)} = 2.77$).

With the establishment of the Plaza Agreement exchange market participants found themselves confronted with a new 'economic reality' of closely cooperating monetary authorities (Funabashi 1988). The empirical evidence suggests that the clear guide for exchange rate expectations embodied in the agreement led to a decline in the volatility of the daily DM/$ rate. At their meeting in the Louvre in Paris on February 22, 1987 central bank presidents and ministers of finance of the G-7 countries agreed to coordinate their economic policy more closely. In the financial press there was talk of the monetary authorities agreeing on certain target zones for the major exchange rates. Obviously, this may have calmed market participants still further and thereby stabilized exchange rate expectations. In the second half of 1987, however, it seemed that the G-3 countries were no longer willing to direct monetary policy towards stabilizing exchange rates. Furthermore, doubt arose about whether financial adjustment was sufficiently backed by internal policy changes aimed at cutting the US 'twin deficit' and current account surpluses in Germany and Japan. The results of some tentative estimations not shown here point to an upturn in volatility after October 1987. The October 1987 stock market crash is likely to have caught exchange market participants off balance. This may be a reason for the not too overwhelming empirical evidence in favour of the stabilizing impact of the Louvre Agreement. In late December 1987 'G-7 officials reached a new set of understandings about fluctuations in exchange rates and cooperation in exchange market operations' (Pauls 1990, p. 907). This has become known as the Telephone Agreement, reflecting the fact that it was not established at a central meeting. The estimation results reported above do not point to a significant difference between the average volatility before and after the Telephone Agreement. The null hypothesis H_0: $\pi_2 = \pi_3$ can not be rejected in a likelihood ratio test. It is possible that market participants viewed the Telephone Agreement of December 22, 1987 as a credible confirmation of policy coordination fitting well in the framework of the Louvre Agreement. They may as well have neglected it because of the meagre announcement effect.

A4.1.4 Conclusions

The results presented in this appendix are in line with recent evidence that the random-walk model with a GARCH error term gives a good description of the statistical properties of daily exchange rate returns in the US dollar—Deutsche Mark market. Modelling the GARCH (1,1) process as a conditional normal distribution takes account of the conditional heteroskedasticity present in daily DM/$ returns. The model can capture the stylized fact of clusters of large values while the conditional variance is modelled as a weighted average of the variance in past periods with geometrically declining weights. Some excess kurtosis is left unexplained by the model. This, however, does not make it impossible to detect some interesting effects of exchange rate policy regime shifts on the unconditional variance of the DM/$ rate. Both the Plaza Agreement and the Louvre Agreement, the latter perhaps not too convincingly in a statistical sense, appear to have acted upon the price formation on the market for foreign exchange.

The estimation results presented above indicate that policy coordination stabilized market participants' expectations leading to a drop in the unconditional variance of daily exchange rate returns. This result, combined with empirical evidence by Bini Smaghi (1991) pointing to a negative effect of short-term exchange rate risk on the volume of international trade, suggests that the world economy is better off since the US monetary authorities abandoned their hands-off policy in February 1985.

APPENDIX A4.2 TECHNICAL DETAILS OF TOBIT ANALYSIS

In Tobit analysis, the likelihood of each subsample has a component for the observations that are positive (or negative, depending on whether the central banks bought or sold US dollars) and a component for the observations that are zero.

For the observations with $INV_t = 0$ it is known that

$$d_0 + d_1 \left(SFR_t^{8.30} - SFR_t^{MA}\right) + d_2\, h_t + \mu_t^* \leq 0,$$

so

$$Pr\ [INV_t{=}0] = Pr \left[\frac{\mu_t^*}{\sigma} \leq \frac{-\,d_0 - d_1 \left(SFR_t^{8.30} - SFR_t^{MA}\right) - d_2\, h_t}{\sigma} \right]$$

$$= 1 - F_t$$

where Pr denotes the expected probability and F_t is the standard normal cumulative density function evaluated at

$$\frac{d_0 + d_1 \left(SFR_t^{8.30} - S_t^{MA}\right) + d_2\, h_t}{\sigma}$$

For the T observations for which INV_t is nonzero an ordinary probability density function applies. The log-likelihood function is given by

$$L = \Sigma_0 \ln\,(1 - F_t) - (\frac{T}{2}) \ln 2\pi - (\frac{T}{2}) \ln \sigma^2 -$$

$$- \Sigma_1 \left[\frac{INV_t - d_0 - d_1 \left(SFR_t^{8.30} - S_t^{MA}\right) - d_2\, h_t}{2\sigma^2} \right]$$

where Σ_0 and Σ_1 denote the sum over the zero observations and the sum over the positive (first subsample for both central banks) or negative (other subsamples) observations, respectively. Amemiya (1973) proves that, if the log-likelihood is maximized, the ML estimators for this model are consistent and asymptotically normal.

NOTES

1. This chapter is based on Almekinders and Eijffinger (1994a).
2. Goodhart and Hesse (1993) reveal some interesting aspects of the timing of foreign exchange intervention.
3. Goodhart and Hesse (1993) assess central bank foreign exchange market intervention virtually in continuous time. However, their investigations are based on *reported* intervention observations which appeared on Reuters screen information. This gives a far from exact representation of actual intervention operations. Moreover, reported intervention observations do not contain information on the *actual* amount of intervention.
4. Data for the opening, fixing and closing dollar—DM rate are taken from: Statistische Beihefte zu den Monatsberichten der Deutschen Bundesbank, Reihe 5: Die Währungen der Welt, Februar 1985—November 1990, Tabelle 6: Kassa-Kurse des US dollar in Tagesverlauf.
5. Data on the official interventions of the Bundesbank and Federal Reserve, to the extent that they affected the net foreign position of the Bundesbank, were kindly provided by the Deutsche Bundesbank, Hauptabteilung Ausland on a confidential basis. Therefore, this study comprises no exact data, nor any figures of these interventions.
6. Empirical evidence on the relation between trade balance announcements and exchange rate movements is presented in, e.g., Hogan et al. (1991), Klein et al. (1991) and Eijffinger and Gruijters (1992).
7. Eijffinger and Gruijters (1991) compare a three-days, five-days and seven-days moving average, respectively. However, the present study concentrates on a seven-days moving average only, because this generally turned out to give the best empirical results.
8. The constant is a consequence of the low frequency of the data on 'fundamentals' (inflation, money growth, balance of payments accounts, etc.). The inclusion of monthly or quarterly data for these variables does not seem to be appropriate in a daily model of exchange market intervention.
9. However, if the smoothing or 'leaning against the wind' coefficient unexpectedly has a positive sign, then the central bank concerned actually reacts by a policy of 'leaning *with* the wind' and thus amplifies the exchange rate volatility in the short run. Such a policy is expected to be an exception.
10. I would argue that exchange rate risk associated with *intraday* exchange rate developments is of major importance when studying noise-trading behaviour and the interaction between central banks and exchange market participants which behave as 'chartists' (see e.g. Allen and Taylor (1990) and Hung (1991a,b) for a more extensive treatment of this subject). An empirical investigation of this interaction would require the use of intradaily data of interventions, exchange rates and even trading volumes.
11. An increase in exchange rate volatility does not necessarily have to lead to a decline in the volume of trade. An income and a substitution effect are at work. The substitution effect of resources shifted away from the traded-goods sector when volatility increases may be dominated by an income effect working in the opposite direction. De Grauwe (1988) shows that this is the case if producers are sufficiently risk averse and increase resources in the export sector to offset the drop in expected utility of export revenue caused by the rise in exchange rate volatility.
12. See Appendix A4.1 for the derivation of this expression for the unconditional variance.
13. Periods of prolonged interventions in one direction were selected to rule out the possibility that 'negative' interventions are simply observed opposite interventions (i.e. selling instead of buying and vice-versa).
14. This appendix is based on Almekinders (1994a).
15. See note 4 for the data source.

5. Objectives of Daily Bundesbank and Federal Reserve Intervention in the DM/$ Market — Part II

5.1 INTRODUCTION[1]

The previous chapter discussed the results of an empirical investigation into the objectives of daily foreign exchange market intervention by the Deutsche Bundesbank and the Federal Reserve System in the US dollar—Deutsche Mark market. This chapter reports on the results of further empirical research into the objectives of interventions conducted by both central banks. This study makes two contributions. Firstly, the central bank intervention reaction function is derived formally rather than postulated *ad hoc*. Secondly, to capture the observed discontinuity in the intervention behaviour of the central banks a friction model is employed. It will become clear that this involves a generalization of Tobit analysis implemented in the previous chapter.

The majority of previous empirical investigations into the objectives of central bank intervention formulate the reaction function rather *ad hoc* (see, e.g. Chapter 4 and the papers surveyed in Chapter 3). This study takes a novel approach. In Section 5.2 the intervention reaction function is derived formally. First, the popular GARCH model for the exchange rate is amended to allow interventions to have an effect on both the mean and the variance of exchange rate returns. Then, a policy loss function for the central bank is combined with this exchange rate model to derive the intervention reaction function. Official purchases (sales) of foreign currency by the domestic central bank appear to depend on two variables. The model implies that they are positively related to the expected fall (rise) of the exchange rate below (above) the target level pursued by central banks and to the volatility of the exchange rate conditional on no intervention.

Section 5.3 describes the daily data on exchange rates and intervention used in this study to investigate the objectives of Bundesbank and Federal Reserve intervention. The sample period considered is the post-Louvre period February 23, 1987 to October 31, 1989. Section 5.3 also introduces the explanatory variables used in the empirical implementation of the model in Section 5.4.

In practice, central banks are rather reluctant to intervene in the foreign exchange market. By abstaining from intervention in the face of small changes in the exchange rate and normal levels of conditional volatility the central banks can be viewed as 'investing' in the potential effectiveness of interventions to be undertaken at times when the foreign exchange market experiences some serious turbulence. This feature of intervention behaviour makes the standard linear regression model an inappropriate tool for estimating the derived reaction function.

To capture adequately this aspect of central banks' behaviour, we employ a friction model devised by Rosett (1959) in which the dependent variable is zero as long as the independent variables remain 'close' to their desired levels. The central banks' tolerance threshold for deviations of the explanatory variables from their desired levels is one of the parameters in the model.

The estimation results reproduce the familiar 'leaning against the wind' policy by the Deutsche Bundesbank and the Federal Reserve. Furthermore, an increase in the conditional variance of daily DM/$ returns is found to have led both central banks to increase the volume of intervention. Finally, the estimation results point to some interesting asymmetries in the intervention behaviour of the Bundesbank and the Federal Reserve.

5.2 THE MODEL

Neumann (1984) implements a flow market model for the determination of the exchange rate. He derives an intervention reaction function according to which the central bank of the home country supplies amounts of home currency to the foreign exchange market when the exchange rate of the foreign currency in terms of the home currency is lower than the target rate ($S_t < S_t^T$) and when an increase in the expected risk premium on assets denominated in the home currency raises speculative demand for that currency. It should be noticed that the serious measurement problems surrounding 'risk premiums' are well established. More importantly, the flow market model and other structural models for exchange rate determination are rejected in empirical tests. This has led many economists to adopt new research strategies in exploring the field of exchange rate economics.

By now, it is well established that a GARCH model offers a parsimonious description of the stochastic process of daily spot exchange rate returns (see, e.g. Baillie and Bollerslev 1989).[2] This chapter focuses on the motives for central bank intervention. Accordingly, it is assumed that interventions can alter both the mean and the conditional variance of daily exchange rate returns. Furthermore, the postulated stochastic process for the exchange rate allows for a GARCH-in-Mean effect:

$$100\,(\Delta \log S_t^U) = \delta_0 + \delta_1\, INV_t - \gamma\, DUM_t\, h_t + \epsilon_t \tag{5.1a}$$

$$\epsilon_t | \Omega_{t-1} \sim N\,(0,\, h_t) \tag{5.1b}$$

$$h_t = \pi - \delta_2\, DUM_t\, INV_t + \alpha\, \epsilon_{t-1}^2 + \beta\, h_{t-1} \tag{5.1c}$$

$$DUM_t = 1\ (-1) \quad \text{if} \quad \Delta \log S_{t-1}^U < 0\ (\geq 0) \tag{5.1d}$$

Throughout this chapter the exchange rate, S_t, is defined as the domestic currency price of one unit of foreign exchange. Subscript t denotes time and lower-case letters refer to natural logarithms of variables. Greek letters denote positive constants. All GARCH models in this chapter are expressed in closing exchange rates (S^U). It follows that the dependent variable in (5.1a) is the exchange rate return over the 24-hour period from the closing of the foreign exchange market on day t—1 until day t's closing. Equation (5.1a) characterizes the mean of the stochastic process which generates the exchange rate return series. δ_0 denotes a constant rate of appreciation of foreign currency. INV_t is the volume of intervention defined as purchases of foreign currency by the domestic central bank. Interventions are effective if $\delta_1 > 0$ implying that purchases (sales) of foreign currency by the domestic central bank lead to a higher (lower) exchange value of foreign currency in terms of domestic currency. ϵ_t is the residual of the mean equation. Equation (5.1b) indicates that it has a conditional normal distribution with mean zero and variance h_t. The symbol Ω_{t-1} denotes the information available to exchange market participants at the beginning of the relevant interval for which the exchange rate return is calculated: the closing of the foreign exchange market on day t—1. When measured over a sufficiently long period, the constant rate of appreciation of domestic currency δ_0 may be approximately zero. Then, large drops in the exchange rate correspond with large negative realizations of ϵ_{t-1}, ϵ_{t-2}, etc. In the case of bandwagon expectations among private exchange market participants, these may lead to a further decline of the exchange rate: the GARCH-in-Mean effect. When the exchange rate was falling (rising) in the previous period(s), a high conditional variance is likely to lead to a larger fall (rise) in the current period. Hence $DUM_t = 1$ ($DUM_t = -1$) in case of a falling (rising) exchange rate. Equation (5.1c) defines the variance equation (h_t). Due to the inclusion of the volume of intervention premultiplied by a dummy variable, this equation can capture the effect of both official sales and purchases of foreign currency. At first glance, less exchange rate volatility and uncertainty seem to be preferable for society as a whole.[3] Hence, interventions are effective if $\delta_2 > 0$. With the dummy variable defined as in equation (5.1d), this indicates that both purchases and sales of foreign currency lower the volatility of returns on the foreign exchange market. Presumably, the interventions work through the expectations channel. They may curb bandwagon expectations and lead to a lowering of the conditional variance. In turn, the dampening effect of interventions on the conditional variance may lead to smaller daily returns on the foreign exchange market, if γ is significantly larger than zero.

Of course, the conduct of exchange rate policy is not the only issue of concern for a central bank. Neumann (1984) proposes a central bank policy loss function which accounts for a trade-off between controlling the monetary base on the one hand and the exchange rate on the other hand. However, in most large industrialized countries the monetary authorities give priority to domestic policy objectives and use instruments of monetary policy to attain these objectives. By definition, sterilized interventions lack a money-market effect (cf. Pilbeam 1991, p. 106). Therefore, it may be an appropriate simplification to focus on the motives for sterilized interventions in the spot market for foreign exchange. Suppose the central bank wishes to limit deviations of the exchange rate from a target level (S_t^T). Its expected policy loss increases more than proportionally with both positive and negative deviations from the target level:

$$E_{t-1}\, L_t^{CB} = E_{t-1}\, (\log S_t - \log S_t^T)^2 \tag{5.2}$$

To capture intervention carried out on account of a 'leaning against the wind' policy, the target level for the exchange rate can be thought of as representing past levels of the exchange rate. This follows immediately from the definition of smoothing exchange rate fluctuations: whether or not the exchange rate was considered to be at a desirable (or target) level in the previous period(s), deviations from this level will be countered.

Minimizing the loss function (5.2) by choosing INV_t subject to the constraints implied by the stochastic process of the exchange rate described by (5.1a)—(5.1d) leads to the following intervention reaction function for the central bank:[4,5]

$$INV_t = \frac{\delta_2\, \phi_1^2}{2}\, DUM_t - \phi_1\, (s_{t-1} + \delta_0 - s_t^T) - \tag{5.3}$$

$$- \phi_1\, \gamma\, DUM_t\, (\pi + \alpha\, \epsilon_{t-1}^2 + \beta\, h_{t-1})$$

where

$$\phi_1 = 1 \,/\, (\delta_1 + \gamma\, \delta_2)$$

and

$$DUM_t = 1\ (-1) \qquad \text{if} \qquad \Delta \log S_{t-1}^U < 0\ (\geq 0).$$

According to equation (5.3) the volume of intervention depends on a constant term which is positive (negative) when the exchange rate was falling (rising) in the previous period. Furthermore, official purchases (sales) of foreign currency by the domestic central bank depend positively on the fall (rise) of the exchange rate below (above) the target level, which is expected to occur during period t conditional on no intervention. Finally, an increase in the conditional variance of the exchange rate (again, conditional on no intervention) leads the domestic central bank *ceteris paribus* either to buy or sell more foreign currency depending on whether the course of the level of the exchange rate calls for purchases or sales of foreign currency.

The intervention reaction function derived in this section will be estimated in Section 5.4 for daily interventions by the Deutsche Bundesbank in the spot Deutsche Mark—US dollar exchange market and by the Federal Reserve System in the spot Deutsche Mark—US dollar exchange market and the spot Japanese yen—US dollar exchange market.[6] Section 5.3 describes the data that is used for the empirical study.

5.3 THE DATA

An empirical study of a reaction function for daily interventions must take account of the development of the respective exchange rates between successive days (interday), as well as in the course of these days (intraday).[7] The objectives of Bundesbank interventions are investigated by linking the direction and volume of Bundesbank interventions to the interday and intraday development in the DM/$ exchange rate. The study makes use of daily observations for interventions by the Deutsche Bundesbank expressed in millions of US dollars.[8] For Bundesbank intervention, the relevant intraday development in the DM/$ exchange rate is approximated by three observations per day in the Frankfurt market:

1. the opening rate (primo) at 8.30 hours (Frankfurt time), $SFR_t^{8.30}$;
2. the fixing rate (official middle rate) at 13.00 hours, $SFR_t^{13.00}$;
3. the closing rate (ultimo) at 16.30 hours (Frankfurt time), $SFR_t^{16.30}$.

Analogously, the objectives of Federal Reserve interventions are investigated by linking the direction and volume of Federal Reserve interventions to the interday and intraday development in the DM/$ exchange rate. The study makes use of daily observations for Federal Reserve interventions in the DM/$ and yen/$ exchange market expressed in millions of US dollars. For Federal Reserve intervention, the intraday development in the DM/$ market and the yen/$ market are approximated by four observations per day in the New York market:

1. the opening rate at 9.00 hours (New York time), SNY_t^9;
2. the first middle rate at 12.00 hours (New York time), SNY_t^{12};
3. the second middle rate at 14.00 hours (New York time), SNY_t^{14};
4. the closing rate at 16.00 hours (New York time), SNY_t^{16}.

In the model presented above a time subscript was attached to the symbol denoting the target exchange rate. This indicates that it is allowed to vary over time. Obviously, when the domestic central bank continues to direct intervention at a fixed target level for the exchange rate while the actual exchange rate is being driven up (i.e., the value of the domestic currency is being driven down) by a strong underlying market sentiment this intervention will in the end lead to a run on the (remaining) foreign exchange reserves of the domestic central bank. At the other extreme, when the central bank stubbornly tries to resist a persistent appreciation of the domestic currency (persistent decline of the exchange rate), it will encounter problems with sterilizing the money-market effect of its increased foreign exchange reserves. Eventually, the central bank will have to tolerate an inflationary effect of the interventions. Thus, while it is assumed that the central bank wishes to limit deviations from a target level, a flexible formulation of the target level (S_t^T) is chosen which seems to be in accordance with the limited manageability of exchange rates in practice:

for Bundesbank interventions

$$SFR_t^{MA} = \frac{1}{21} \sum_{n=1}^{7} (SFR^{8.30} + SFR^{13.00} + SFR^{16.30})_{t-n}^{DM/\$}$$

for Federal Reserve interventions

$$SNY_t^{MA} = \frac{1}{28} \sum_{n=1}^{7} (SNY^{9} + SNY^{12} + SNY^{14} + SNY^{16})_{t-n}^{DM/\$,\ yen/\$}$$

The target level for the exchange rate is thought of as representing past levels of the exchange rate. This is not to say that the exchange rate was considered to be at a desirable level in previous days. It merely provides a base for testing whether the central banks systematically 'leaned against the wind' and tried to smooth (further) deviations from the seven-days moving average of the exchange rate.

The reaction function in equation (5.3) proposes a second variable to explain the volume of intervention: the conditional variance of the respective exchange rate returns conditional on no intervention. Time series for the conditional variance of daily DM/$ returns (in the Frankfurt and New York market) and yen/$ returns (in New York) are generated using the estimated parameter values of a standard GARCH model depicted in Table 5.1. For the time series $h_t^{FR,\ DM/\$}$, $h_t^{NY,\ DM/\$}$ and $h_t^{NY,\ yen/\$}$, the unconditional or average variance of the return series for the sample considered in Table 5.1, σ^2, is used as a starting value. It is calculated as follows $\sigma^2 = \pi/(1-\alpha-\beta)$.

The establishment of the February 22, 1987 Louvre Accord marks the beginning of a new exchange rate policy regime. Estimation results presented in Appendix A4.1 point to a marked change in the stochastic process which generates the daily DM/$ return series as of that date.

Table 5.1 Maximum likelihood estimates for the parameters of the standard GARCH model

$$100\ (\log S_t^U - \log S_{t-1}^U) = a_0 + \epsilon_t$$

$$\epsilon_t \mid \Omega_{t-1} \sim N(0, h_t)$$

$$h_t = \pi + \alpha\, \epsilon_{t-1}^2 + \beta\, h_{t-1}$$

	a_0	π	α	β	log L	Q(12)	$Q^2(12)$	m_3	m_4	LR(2)
DM/$ in Frankfurt	0.015 (0.65)	0.021 (2.77)	0.073 (4.47)	0.874 (31.51)	–649.3	10.29	20.63	0.04	4.29	35.68
DM/$ in New York	0.013 (0.54)	0.020 (2.83)	0.064 (4.13)	0.890 (34.83)	–648.8	7.47	6.88	–.09	4.65	25.94
Yen/$ in New York	–0.006 (–.23)	0.043 (3.12)	0.083 (4.21)	0.834 (20.23)	–730.3	5.72	8.07	–.13	5.21	42.41

Notes: See Table 4.2.

Furthermore, it appeared that the process remained relatively stable through to October 1989. Therefore, the sample period chosen is from February 23, 1987 through to October 31, 1989. This period comprises 677 observations for the Frankfurt market and 680 observations for the New York market. The estimated coefficients for the GARCH models shown in Table 5.1 are highly significant with the exception of the coefficient in the mean equation (a_0). The DM/\$ rate and the yen/\$ rate did not rise or decline uniformly across the sample. The value of the likelihood ratio (LR) test statistic in the last column of Table 5.1 indicates that the null hypothesis $H_0 : \alpha = \beta = 0$ can be soundly rejected. This indicates that the random-walk model with a GARCH error term fits the data better than the Gaussian random walk.

The variance of a variable is positive by definition. However, central banks will react differently to rises in the conditional variance of exchange rate returns depending on the level of the exchange rate. For instance, when the exchange rate is 'too high' ('too low') central banks are likely to respond to a rise in the conditional variance by selling (buying) foreign exchange. In order to facilitate a straightforward interpretation of the estimated coefficient for the conditional variance in the intervention reaction function the conditional variance h_t is premultiplied with a dummy variable which takes on a value 1 (—1) if the exchange rate is above (below) the Louvre-equilibrium level. The latter is approximated by the opening exchange rates in New York on February 23, 1987: \$1 = DM 1.8255 and \$1 = ¥ 153.4, respectively.

5.4 ESTIMATION AND RESULTS

The intervention reaction functions for the Bundesbank (DBB) and the Federal Reserve System (FED) implied by the model in Section 5.2 and the description of the data in Section 5.3 can be written:

$$INV_t^{DBB} = b_0\, DUM_t + b_1\, (100 * (\log(SFR_t^{8.30}) - \log(SFR_t^{MA}))) + b_2\, DL_t\, h_t^{FR} + \mu_t \tag{5.4}$$

$$INV_t^{FED} = c_0\, DUM_t + c_1\, (100 * (\log(SNY_t^{9}) - \log(SNY_t^{MA}))) + c_2\, DL_t\, h_t^{NY} + \mu_t \tag{5.5}$$

where $DUM_t = 1$ (—1) if $\Delta\, s_{t-1}^{U} < 0$ (≥ 0), μ_t is a random disturbance term and the dummy variable DL_t is defined as follows:

$$DL_t = 1 \quad \text{if} \quad S_t^{DM/\$} \geq S_{LOUVRE}^{DM/\$} \text{ or } S_t^{yen/\$} \geq S_{LOUVRE}^{yen/\$}$$

$$= -1 \quad \text{if} \quad S_t^{DM/\$} < S_{LOUVRE}^{DM/\$} \text{ or } S_t^{yen/\$} < S_{LOUVRE}^{yen/\$}$$

In practice, central banks are rather reluctant to intervene in the foreign exchange market. This may stem from the fact that typical intervention efforts, which are of the order of \$100 or \$200 million, are very tiny compared to the average daily turnover on foreign exchange markets. As a consequence of the relative negligibility of interventions, their impact on the course of exchange rate movements depends crucially on the strength of their announcement effect on the expectations of private exchange market participants. Hence, it seems reasonable to assume that the more frequently a central bank intervenes, the less attention will be paid to the message contained in the official foreign currency operations. It follows that the central bank is faced with a trade-off. It can choose to intervene more frequently in the present with a (small) chance of driving the current spot rate closer to the target rate and/or limiting the conditional volatility of the spot exchange rate. This will go at the cost of lowering the 'news'-content and thus the potential effectiveness of future interventions. Thus, by abstaining from intervention in the face of small changes in the exchange rate and normal levels of conditional volatility, the central banks can be viewed as 'investing' in the potential effectiveness of interventions to be undertaken at times when the foreign exchange market experiences some serious turbulence.

The large proportion of zero observations for the dependent variable in the intervention reaction functions despite nonzero values of the explanatory variables is inconsistent with the continuous density specification of (5.4) and (5.5). Therefore, the use of ordinary least squares as an estimation technique yields biased and inconsistent estimates. Rosett (1959) developed a friction model to suitably account for relationships in which the dependent variable is insensitive to small realizations of the explanatory variables.[9] In matrix notation:

$$\begin{aligned}
INV &= (\mathbf{X\Omega} + \mu) - \Theta^{+} && \text{if} \quad (\mathbf{X\Omega} + \mu) > \Theta^{+} \\
INV &= 0 && \text{if} \quad \Theta^{-} \leq (\mathbf{X\Omega} + \mu) \leq \Theta^{+} \\
INV &= (\mathbf{X\Omega} + \mu) - \Theta^{-} && \text{if} \quad (\mathbf{X\Omega} + \mu) < \Theta^{-}
\end{aligned}$$

where *INV* is the dependent variable, **X** is the matrix of explanatory variables, $\mathbf{\Omega}$ is a vector of coefficients, μ is a vector of normal, i.i.d. errors and $\Theta^{+}(>0)$ and $\Theta^{-}(<0)$ are the thresholds which must be exceeded before the central bank acts to buy or sell foreign currency, respectively. In the actual estimation of the friction model the thresholds replace the positive and negative constant terms in equations (5.4)—(5.5).

Maximizing the likelihood function of the friction model provides estimates of the tolerance thresholds, the standard deviation of the disturbance term, σ_μ, and the coefficient vector on the explanatory variables, Ω. The likelihood function of the friction model consists of three components. For the observations for which *INV* is positive (first component) and the observations for which *INV* is negative (third component) an ordinary probability density function applies. For the observations with *INV* = 0 we know that $\Theta^- \leq (\mathbf{X\Omega} + \mu) \leq \Theta^+$. Consequently,

$$\begin{aligned} Pr\ [INV_t = 0] &= Pr\ [\theta^- \leq X\Omega + \mu \leq \theta^+] \\ &= \Phi\left(\frac{\theta^+ - X\Omega}{\sigma}\right) - \Phi\left(\frac{\theta^- - X\Omega}{\sigma}\right) \end{aligned}$$

where *Pr* denotes the expected probability and Φ is the standard normal cumulative density function. The likelihood function can be written:

$$L = \prod_{INV>0} \frac{1}{\sigma\sqrt{(2\pi)}}\, e^{\frac{-(INV + \theta^+ - X\Omega)^2}{2\sigma^2}} * \prod_{INV=0} \left\{\Phi\left(\frac{\theta^+ - X\Omega}{\sigma}\right) - \Phi\left(\frac{\theta^- - X\Omega}{\sigma}\right)\right\}$$

$$* \prod_{INV<0} \frac{1}{\sigma\sqrt{(2\pi)}}\, e^{\frac{-(INV + \theta^- - X\Omega)^2}{2\sigma^2}}$$

The maximum likelihood estimates for the parameters of the friction model for central bank intervention are reported in Table 5.2. The Bundesbank and the Federal Reserve are clearly found to have conducted a 'leaning against the wind' policy during the post-Louvre sample period from February 23, 1987 to October 31, 1989. The coefficients for the explanatory variable which captures deviations of day *t*'s opening exchange rate from the seven-days moving average have the expected negative sign both for Bundesbank intervention in the DM/$ market and for Federal Reserve intervention in the DM/$ and yen/$ market and are statistically significant in all cases. A one percentage point appreciation (depreciation) of the US dollar *vis-à-vis* the Deutsche Mark above (below) its moving average on average led the Bundesbank to sell (buy) $79.77 million in the DM/$ market and the Federal Reserve to sell (buy) $106.91 million. The equivalent figure for Federal Reserve intervention in response to changes in the yen/$ rate is $99.25 million.

The estimation results indicate that both central banks actively responded to increases in the anticipated volatility of the exchange market. In effect, the Federal Reserve's reaction to exchange rate

Table 5.2 Maximum likelihood estimates for the parameters of the friction model for central bank intervention

Explanatory variables	Bundesbank intervention in DM/$ market		Federal Reserve intervention in DM/$ market		Federal Reserve intervention in yen/$ market	
deviations from moving average	–79.77 (–9.27)		–106.91 (–8.76)		–99.25 (–9.15)	
positive deviations		–55.07 (–3.44)		–121.55 (–6.07)		–138.80 (–5.09)
negative deviations		–103.65 (–6.56)		–92.75 (–4.74)		–69.87 (–4.80)
conditional variance	–221.07 (–8.30)	–224.96 (–8.27)	–383.92 (–8.46)	–381.99 (–8.37)	–393.00 (–8.00)	–383.17 (–8.16)
positive threshold (Θ^+)	381.79 (12.31)	406.91 (10.94)	509.97 (10.61)	493.70 (9.56)	516.02 (10.82)	472.51 (10.09)
negative threshold (Θ^-)	–226.79 (–11.65)	–205.32 (–8.99)	–315.47 (–9.58)	–327.10 (–9.00)	–361.80 (–8.66)	–394.28 (–8.47)
σ	196.32 (18.65)	195.69 (18.72)	218.51 (14.51)	217.77 (14.39)	220.53 (17.64)	216.21 (18.25)
logL	–1300.2	–1298.7	–1168.4	–1168.0	–1037.7	–1034.9
LR(1) for equality		2.96		0.74		5.62

Notes:

t-statistics in parentheses.

LR(1) gives the value of the test statistic for the likelihood ratio test under the nullhypothesis that the coefficients for positive and negative deviations from the moving average are equal. The LR(1)-statistic has a χ^2-distribution with one degree of freedom. The tabulated critical value for a 5% (10%)-level test is 3.84 (2.71).

uncertainty was considerably stronger than that of the Bundesbank. For example, given that the DM/$ rate was above the longer-term target rate implied by the Louvre Agreement, an increase in the conditional variance of one point, say from 0.40 to 0.41, caused by a larger than average percentage change in the DM/$ rate during the previous days on average induced the Bundesbank to sell $2.21 million, while it led the Federal Reserve to sell $3.84 million in the DM/$ market, *ceteris paribus*.

The estimation results confirm the seeming reluctance of central banks to intervene despite deviations of current exchange rates from their moving average and changes in the conditional variance of exchange rate returns. The tolerance thresholds for intervention (Θ^+ and Θ^-, for purchases and sales of US dollars, respectively) of the Bundesbank and the Federal Reserve reported in Table 5.2 are all statistically significant. The thresholds for Bundesbank intervention are smaller than those for interventions by the Federal Reserve. This is due to the fact that on some trading days in the sample the German central bank intervened at the fixing of the Frankfurt market for foreign exchange in small amounts (of the order of DM 5 to 10 million). These interventions have a technical character and are not always policy motivated. However, they do artificially lower the thresholds for Bundesbank intervention. The Fed's higher threshold, in absolute value, for purchases of US dollars could be interpreted as evidence of its concern with the competitiveness of US exporting firms. In addition, given the already high US trade deficit, the Federal Reserve may have been relatively more opposed to an appreciation of the US dollar *vis-à-vis* both the DM and the yen.

An asymmetry in both Bundesbank and Federal Reserve intervention policy becomes apparent when a distinction is made between positive and negative deviations from the seven-days moving average. From Table 5.2 it is obvious that both central banks tried to counteract appreciations of their own currency more strongly than depreciations. Given that the investigations in this chapter focus on a post-Louvre episode it is useful to keep in mind that the Louvre Agreement embodied a commitment to stabilize the value of the dollar at its then prevailing level and contain the steep decline induced by the Plaza Agreement of September 22, 1985. The Federal Reserve did indeed counteract depreciations of the US dollar *vis-à-vis* the Deutsche Mark and the Japanese yen ('negative deviations from moving average'). However, the estimation results indicate that its intervention efforts in response to appreciations of the US dollar in the DM/$ and ¥/$ market exceeded those in response to depreciations by 30 and 50 per cent, respectively. It should be noted that in the case of Federal Reserve intervention in the DM/$ market the intervention efforts are not significantly different at usual levels of significance. For the

Bundesbank it was relatively easy to hang on to its Louvre commitment. By supporting the value of the dollar it simultaneously prevented a deterioration in the international competitiveness of German industries.

5.5 CONCLUSIONS

This chapter derives a central bank intervention reaction function by combining an amended GARCH model for the exchange rate with a loss function for the central bank. Consistent estimation results are obtained by implementing a friction model. This made it possible to cope with the fact that the Bundesbank and the Federal Reserve refrain from engaging in any transaction in the foreign exchange market on the majority of trading days in the post-Louvre sample considered. Using daily exchange rate and intervention data it is found that the German and US central bank 'leaned against the wind' in the DM/$ market and the DM/$ and yen/$ markets, respectively. In addition, it is found that the central banks took into account the well-established empirical finding that exchange rate volatility is predictable to some extent. The estimation results suggest that both the Bundesbank and the Federal Reserve have taken action to lower exchange market uncertainty.

NOTES

1. This chapter is based on Almekinders and Eijffinger (1994b).
2. GARCH stands for Generalized Autoregressive Conditionally Heteroskedastic. The purport of the meanwhile extensive GARCH literature, surveyed in Bollerslev et al. (1992), is that volatility in daily returns is predictable in most financial markets. In several applications it has been shown that there is a considerable persistence in the effects of shocks in period t onto the conditional variance of exchange rates in consecutive periods.
3. Of course, one can easily think of situations in which central banks prefer a higher degree of uncertainty regarding the future course of currency movements. According to Blundell-Wignall and Masson (1985, p. 156) 'it may be a deliberate part of an intervention strategy to change the degree of uncertainty concerning exchange rate fluctuations: either by limiting transitory fluctuations and hence providing a more stable planning environment, or by adding an erratic element to exchange rate movements, to discourage speculation'.
4. The variance of a random variable X can be expressed as $Var\ (X) = E\ (X^2) - (EX)^2$. Consequently, equation (5.2) can be rewritten as follows

$$E_{t-1}[(s_t - s_t^T)^2] = \left[E_{t-1}(s_t - s_t^T)\right]^2 + Var_{t-1}(s_t - s_t^T)$$

$$= \left[s_{t-1} - s_t^T + a_0 + \delta_1\, INV_t - \gamma\, DUM_t\, h_t\right]^2 + h_t$$

5. The second-order conditions for a minimum are met. Given the quadratic form of the loss function, the minimum is global.
6. The Japanese monetary authorities stick to a policy of strict confidentiality regarding intervention data. Therefore, it is not possible to investigate empirically the reaction function for daily interventions by the Bank of Japan in the spot US dollar—Japanese yen exchange market.
7. Goodhart and Hesse (1993) assess central bank foreign exchange market intervention virtually in continuous time. However, their investigations are based on *reported* intervention observations which appeared on Reuters screen information. This gives a far from exact representation of actual intervention operations (Klein 1993, Osterberg and Wetmore Humes 1993). Moreover, reported intervention observations do not contain information on the actual amount of intervention.
8. Originally, the Bundesbank intervention data are expressed in millions of Deutsche Marks. In this study the dollar value of Bundesbank interventions is used as the dependent variable. The dollar value is calculated by dividing the DM value of day t's intervention by the opening rate of the US dollar in Frankfurt on day t.
9. Rosett (1959, p. 263) mentions the example of small changes in yield not leading to changes in the holdings of a particular asset by a certain class of investors because of transaction costs. Forbes and Mayne (1989) estimate a friction model of the prime rate. The interest rates on bank loans under $1,000,000 to businesses are mostly tied to the prime rate which has a tendency to remain unchanged despite movements in, for instance, the secondary market rate on large, negotiable certificates of deposit. Feinman (1993) estimates a friction model for the volume of daily open market operations conducted by the Federal Reserve Open Market Desk. The Desk refrains from engaging in any transaction on roughly one day in four.

6. Effectiveness of Daily Bundesbank and Federal Reserve Intervention in the DM/$ Market

6.1 INTRODUCTION[1]

Chapters 4 and 5 investigated empirically the objectives of Bundesbank and Federal Reserve interventions. Both central banks were found to have 'leaned against the wind'. After having established that, it is natural to ask the question whether the interventions carried out by the Bundesbank and the Federal Reserve were effective. A lot of effort has been devoted to investigating the effectiveness of central bank intervention (for surveys of the literature, see Edison 1993, Edison et al. 1994 and Chapter 3 of this book). Straightforward estimation of the effect of interventions on contemporaneous exchange rate movements only obtains consistent estimation results if the interventions *cause* contemporaneous exchange rate movements and not the other way around. Obviously, however, it can not be ruled out *a priori* that contemporaneous exchange rate movements are one of the factors which trigger interventions. Some studies disregard this (see, e.g. Dominguez and Frankel 1993a, p. 115 and p. 127). As a result, the estimation results reported in these studies are subject to simultaneity bias. The empirical investigations which do provide consistent estimates basically measure the perceived spot rate effects of interventions indirectly through a risk premium (see, e.g. Dominguez and Frankel 1993b). However, the measurement problems for risk premia are well established.

This chapter reports on the results of an empirical investigation into the effectiveness of official intervention by the Deutsche Bundesbank and the US Federal Reserve System in the Deutsche Mark—US dollar spot exchange market. This study makes two contributions to understanding and testing the effectiveness of central bank interventions. Firstly, the simultaneity problem between exchange rates and interventions is addressed explicitly by implementing a test procedure proposed by Vella (1993). Secondly, the direct effect of intervention on the level of the exchange rate is estimated. Daily observations for the official interventions and the exchange rate are used. The period under consideration runs from the Louvre Agreement of February 22, 1987 to October 1989.

This chapter is organized into five remaining sections. Section 6.2 develops the framework within which the effectiveness of central bank intervention is analysed. Section 6.3 discusses the simultaneity problem. Section 6.4 sets out and implements an estimation procedure proposed by Vella (1993) to test for simultaneity in a model with a censored endogenous regressor. Section 6.5 reports on the results of an empirical investigation into the immediate impact of interventions by the Bundesbank and the Federal Reserve on the level of the DM/$ rate by altering market expectations. Section 6.6 concludes the discussion.

6.2 MODELLING THE EFFECTIVENESS OF FOREIGN EXCHANGE INTERVENTION

Under the assumption of highly efficient markets, effective interventions will influence exchange rate movements immediately (that is, within the same day) by altering the expectations of market participants. Thus, the intraday change of the DM/$ exchange rate in Frankfurt can be written as a function of, *inter alia*, the volume of intervention carried out by the Deutsche Bundesbank on day t (INV_t^{DBB}):

$$SFR_t^{16.30} - SFR_t^{8.30} = f\,(INV_t^{DBB},\ x) \tag{6.1}$$

where x is a set of unspecified exogenous variables.[2] $SFR_t^{8.30}$ and $SFR_t^{16.30}$ are the opening spot rate and the closing spot rate of one US dollar expressed in DM at the Frankfurt exchange, collected at 8.30 hours and 16.30 hours (Frankfurt time), respectively. The exchange market interventions by the Bundesbank are expressed in millions of DMs. The interventions are positive if the central bank buys dollars in return for DMs. The Bundesbank and the Federal Reserve will often coordinate their intervention efforts. Yet, it seems reasonable to assume that the Federal Reserve only intervenes when the New York market is opened. Therefore, the effect of Federal Reserve intervention has to be measured by its impact on the exchange rate on the New York market.

Based on the foregoing, the effectiveness of Bundesbank intervention can be tested by estimating the following equation:

$$SFR_t^{16.30} - SFR_t^{8.30} = a_0 + a_1\ INV_t^{DBB} + a_2\ (SFR_{t-1}^{16.30} - SFR_{t-1}^{8.30}) + \delta_t \tag{6.2}$$

where δ_t is a residual and a_0 and a_1 are coefficients. Equation (6.2) is a restricted form of equation (6.1). It focuses on interventions which reverse unwanted exchange rate movements. This reflects the fact that a narrow definition of effectiveness of intervention is adopted in this chapter. Consequently, official exchange market operations which only slow down unwanted exchange rate movements are not identified as successful interventions. However, by solving the definitional problem we can not get away with the familiar methodological problem that the fluctuations in the exchange rate that would have occurred in the absence of intervention can not be observed. If the Bundesbank is able to influence the market sentiment, the exchange rate will rise after the news of official dollar purchases. Therefore, in that case the intervention coefficient a_1 will be positive. The coefficient a_2 will be significantly larger than zero for periods in which the exchange rate experienced a trend-like appreciation or depreciation.

Analogously, the equation for the effectiveness of Federal Reserve intervention can be written:

$$(SNY_t^{16.00} - SNY_t^{9.00})_{DM/\$} = b_0 + b_1\ INV_t^{FED,\ DM/\$} + b_2\ (SFR_{t-1}^{16.00} - SFR_{t-1}^{9.00})_{DM/\$} + \delta_t \tag{6.3}$$

where $SNY_t^{16.00}$ and $SNY_t^{9.00}$ are the opening spot rate and the closing spot rate of one US dollar expressed in Deutsche Marks at the New York exchange, collected at 9.00 hours and 16.00 hours (New York time), respectively. The exchange market interventions by the Federal Reserve are expressed in millions of US dollars. The interventions are positive if the Federal Reserve buys dollars in return for Deutsche Marks. Again, the intervention coefficient b_1 will be positive when interventions are effective. A positive value of b_2 indicates trends in the exchange rate.

The Federal Reserve also regularly intervenes in the Japanese yen/US dollar market. The effectiveness of these interventions can be inferred from the estimation results of the following equation:

$$(SNY_t^{16.00} - SNY_t^{9.00})_{yen/\$} = c_0 + c_1\ INV_t^{FED,yen/\$} + c_2\ (SFR_{t-1}^{16.00} - SFR_{t-1}^{9.00})_{yen/\$} + \delta_t \tag{6.4}$$

where $SNY_t^{16.00}$ and $SNY_t^{9.00}$ are the opening spot rate and the closing spot rate of one US dollar expressed in Japanese yens at the New York exchange, collected at 9.00 hours and 16.00 hours (New York time), respectively. The exchange market interventions by the Federal Reserve are expressed in millions of US dollars. The interventions are positive if the Federal Reserve buys dollars in return for Japanese yens. The interpretation of the coefficients in equation (6.4) is the same as in equation (6.3)

The daily data on interventions of the Bundesbank and the Federal Reserve in the DM/$ exchange market over the period February 1987 to October 1989 show that interventions were concentrated in specific months and thus that periods of intervention were alternated by (sometimes longer) periods of non-intervention. Moreover, the interventions in these relatively short periods were one-sided (either purchases or sales). Thus it may be concluded that neither the Bundesbank (although intervening more frequently and in larger amounts), nor the Federal Reserve intervened only to smooth exchange rate movements, but also tried to influence the exchange rate (or market sentiment) in a specific direction towards an equilibrium value (which eventually was implied by the February 1987 Louvre Agreement of the G-7 countries).

The portfolio balance channel of intervention derives its effect from creating an imbalance in wealth-holders' portfolios. Accordingly, interventions will have a proportionate effect on the exchange rate which is constant over time. By contrast, in the case of the expectations channel much depends on the strength of the market sentiment. Consequently, the effect of intervention working via this channel will vary over time. To allow for a time-varying effect of intervention, four periods of at least three months with prolonged interventions in one direction by either of the central banks have been selected as relevant subsamples.

6.3 THE SIMULTANEITY PROBLEM

In general, when one wants to make inferences about the effectiveness of foreign exchange market intervention one explicitly has to address the simultaneity problem. Equations (6.2), (6.3) and (6.4) can be estimated consistently with ordinary least squares (OLS) only if interventions *cause* contemporaneous exchange rate movements and not the other way around.[3] Obviously, however, it can not be ruled out *a priori* that contemporaneous exchange rate movements are one of the factors which drive interventions. At the same time, it should be stressed that the specific form of the reduced-form equations (6.2)—(6.4) for the effectiveness of intervention reduces the potential simultaneity problem compared to that in other studies.

Dominguez and Frankel (1993a) try to infer the effectiveness of Bundesbank and Federal Reserve intervention. They estimate with OLS an equation in which the dependent variable is the 24-hour DM/$ return (see Chapter 3, equation (3.18)). Baillie and Humpage (1992) estimate a

GARCH model in which the dependent variable also is the 24-hour DM/\$ return. Their model can be written:

$$100\ (\Delta \log SNY_t^{16.00}) = a_0 + a_1\ INV_t^{DBB + FED} + \epsilon_t \tag{6.5a}$$

$$\epsilon_t \mid \Omega_{t-1} \sim N(0,\ h_t) \tag{6.5b}$$

$$h_t = \pi + a_2\ IPUR_t^{DBB + FED} + a_3\ ISAL_t^{DBB + FED} + \alpha\ \epsilon_{t-1}^2 + \beta\ h_{t-1} \tag{6.5c}$$

with π, α, $\beta > 0$, $\alpha + \beta < 1$. $SNY_t^{16.00}$ denotes the closing rate of the US dollar in Deutsche Marks in New York on day t. Equation (6.5a) represents the mean equation of the model. The dependent variable is the DM/\$ return during a global, 24-hour trading day; from the closing of the New York foreign exchange market on day t—1 until the closing on day t. $INV_t^{DBB+FED}$ is the sum of the volume of US dollar interventions carried out by the Deutsche Bundesbank and by the Federal Reserve Bank of New York, acting on behalf of the Federal Reserve System, respectively. The interventions are positive if the central bank buys dollars in return for Deutsche Marks. Thus, interventions are effective if $a_1 > 0$ implying that purchases (sales) of US dollars by the central bank(s) led to a higher (lower) exchange value of the US dollar in terms of Deutsche Marks. ϵ_t is the residual of the mean equation. Equation (6.5b) states that this residual has a conditional normal distribution with mean zero and variance h_t. Ω_{t-1} indicates the information available to exchange market participants as of the beginning of the relevant interval for which the DM/\$ return is calculated, i.e. the closing of the New York foreign exchange on day t—1. Equation (6.5c) defines the variance equation (h_t). According to Baillie and Humpage, official purchases of US dollars ($IPUR_t > 0$) are effective if they lower the volatility of daily DM/\$ returns. Hence, a_2 should be negative. Analogously, official sales of US dollars ($ISAL_t < 0$) are effective if a_3 is positive.

It was noted in Chapters 4 and 5 that the GARCH model can take account of the persistence in the effects of shocks in period t onto the conditional variance in later periods. Baillie and Humpage (1992) find the GARCH parameters (π, α, β) to be statistically significant. They implement appropriate econometric techniques to obtain unbiased and consistent estimation results in spite of the fact that interventions and exchange rates are jointly determined. There is one serious problem that remains. The exchange rate return, which is the dependent variable in their model, is calculated from the closing of the New York exchange on day t—1 onwards. However, day t's interventions (those carried out by the Federal Reserve in particular) are mostly carried out in the United

States segment of the global foreign exchange market, after the opening of the New York exchange market, i.e. during the last 8 hours of the 24-hour period for which the exchange rate return is calculated. Consequently, the period for which the DM/$ return is calculated does not exactly match the period during which the central banks carry out their interventions. Therefore, it is not strange that Baillie and Humpage find statistically significant *but systematically wrongly signed* coeffients for the intervention variables in both the conditional mean equations and the conditional variance equations. Perhaps a reasonable interpretation of Baillie and Humpage's estimation results is that central bank interventions have *reacted* to earlier exchange rate developments rather than *caused* them. This suggests that the exchange rate equation embodied in the GARCH model is a degenerated intervention reaction function. Indeed, when the estimated coefficients are viewed as coming from an intervention reaction function they are almost all statistically significant with the correct sign.

Dominguez (1993) tries to infer the effectiveness of Bundesbank, Federal Reserve and Bank of Japan interventions from a similar GARCH model. She does not use matching exchange rate and intervention data either. Therefore, she also finds wrongly signed coefficients for the effect of intervention on the level of the exchange rate.

Using the intervention reaction function developed in the previous chapters, the relevant simultaneous equation model is given by

$$S_t^U - S_t^P = \alpha_0 + \alpha_1 \, INV_t + \alpha_2 \, (S_{t-1}^U - S_{t-1}^P) + \epsilon_t \tag{6.6}$$

$$INV_t^* = \beta_0 + \beta_1 \, (S_t^P - S_t^{MA}) + \beta_2 \, (S_t^U - S_t^P) + \mu_t^* \tag{6.7}$$

where ϵ_t and μ_t^* are identically and independently distributed random variables with mean zero and constant variance σ_ϵ^2 and σ_μ^2, respectively.[4] S_t^P and S_t^U are day *t*'s opening (primo) and closing (ultimo) rate, respectively, on the Frankfurt or the New York foreign exchange market depending on whether the regression is concerned with the effectiveness of Bundesbank or Federal Reserve intervention. Equation (6.7) is an intervention reaction function. Accordingly, the central bank 'leans against the wind' and acts upon increases in the conditional variance of the exchange rate. S_t^{MA} is a moving average of exchange rate quotations during the trading hours of the relevant foreign exchange market on previous days. When day *t*'s opening spot exchange rate is above (below) the moving average of the exchange rate on previous trading days the central bank is expected to carry out sales (purchases) of domestic currency. Consequently, the coefficient β_1 is expected to be negative. The term $(S_t^P - S_t^{MA})$ is derived from values of the relevant exchange rate which were known (by the central bank) at the time day t's interventions were carried out. This is not the case with the term $(S_t^U - S_t^P)$ in equation (6.7).[5] It follows that in this equation allowance is made for contemporaneous exchange rate movements causing current interventions.

INV_t and INV_t^* are observed and 'desired' intervention, respectively. On the majority of trading days in the sample (677 in the Frankfurt market and 673 in the New York market, respectively) the volume of intervention by either of the central banks is equal to zero. A possible explanation for the large number of zero interventions is that the central bank does not carry out foreign exchange market operations intended to alter the course of the exchange rate until the perceived necessity to step into the market exceeds a certain threshold level. This necessity can not be observed, however. This is also the case with 'negative' interventions which correspond to various levels of necessity below the threshold level.[6] The relationship between observed and necessary intervention applying to both buying and selling of foreign exchange is

$$\begin{aligned} INV_t &= INV_t^* \text{ if } INV_t^* > 0 \\ &= 0 \quad\;\; \text{ if } INV_t^* \leq 0 \end{aligned} \tag{6.8}$$

Interventions are effective if purchases (sales) of US dollars by the Bundesbank or the Federal Reserve lead to a rise in the value of the US dollar expressed in Deutsche Marks or Japanese yen, i.e. if the estimated value of the coefficient α_1 in equation (6.6) is significantly larger than zero. However, if $\beta_2 \neq 0$, INV_t^* is endogenous and thus INV_t can not be treated as an exogenous variable in (6.6). Estimation of (6.6) with Ordinary Least Squares (OLS) will not be consistent. One solution to this problem is full Maximum Likelihood (ML) estimation of the model made up of equations (6.6) and (6.7).[7] This is computationally not very attractive, particularly while only a test for endogeneity is required. In the next section a test procedure is implemented to address the simultaneity problem between exchange rates and intervention. The test procedure is rather technical. For the reader who wishes to skip this section the results of the test can be summarized as follows. The results of implementing the test procedure do not give rise to rejection of the null hypothesis H_0: $\beta_2 = 0$, i.e. the hypothesis of no endogeneity in the volume of daily Bundesbank and Federal Reserve intervention. Therefore, Section 6.5 proceeds by assuming that equation (6.6) and hence equations (6.2)—(6.4) can be estimated consistently with OLS.

6.4 TESTING FOR SIMULTANEITY BETWEEN EXCHANGE RATES AND INTERVENTION

In this section the test procedure proposed by Vella (1993) is implemented to address the simultaneity problem between exchange rates and intervention. The test procedure involves taking conditional expectations in (6.6); conditioning on both predetermined variables $((S_t^P - S_t^{MA}), (S_{t-1}^U - S_{t-1}^P))$ and INV_t. This gives

$$E\left((S_t^U - S_t^P) \mid (S_t^P - S_t^{MA}), (S_{t-1}^U - S_{t-1}^P), INV_t\right) = \alpha_0 + \alpha_1 INV_t + \\ + \alpha_2 (S_{t-1}^U - S_{t-1}^P) + E\left(\epsilon_t \mid (S_t^P - S_t^{MA}), (S_{t-1}^U - S_{t-1}^P), INV_t\right) \tag{6.9}$$

On the assumption that ϵ_t exhibits no autocorrelation (which holds in general for short-term exchange rate returns, see Hsieh 1989) and that $(S_t^P - S_t^{MA})$ is correctly excluded from (6.6), the conditional expectation on the right-hand side of (6.9) is nonzero only if INV_t is endogenous.

To test this, it is convenient to have a reduced form for (6.7) in which INV_t (INV_t^*) is explained by $(S_t^P - S_t^{MA})$ and $(S_{t-1}^U - S_{t-1}^P)$ only. Substitution of (6.6) in (6.7) obtains

$$INV_t^* = \beta_0 + \beta_1 (S_t^P - S_t^{MA}) + \beta_2\alpha_0 + \beta_2\alpha_1 INV_t + \\ + \beta_2\alpha_2 (S_{t-1}^U - S_{t-1}^P) + (\beta_2\epsilon_t + \mu_t) \tag{6.10}$$

or

$$INV_t^* = z_t'\gamma + \gamma_2 INV_t + \nu_t \tag*{(6.10)'}$$

where $z_t' = [1 \ (S_t^P - S_t^{MA}) \ (S_{t-1}^U - S_{t-1}^P)]$, $\gamma_2 = [\beta_2 \ \alpha_1]$ and $\nu_t = \beta_2 \epsilon_t + \mu_t$. Starting from the assumption that ϵ_t and μ_t are independent, the error term ν_t in (6.10)' will be correlated with the error term ϵ_t in (6.6) only if $\beta_2 \neq 0$ (endogeneity). Rewriting (6.10)', obtains

$$INV_t^* - \gamma_2 INV_t = z_t'\gamma + \nu_t \tag*{(6.10)''}$$

thus

$$INV_t^* = z_t' \frac{\gamma}{1-\gamma_2} + \frac{\nu_t}{1-\gamma_2} \qquad \text{if } INV_t^* > 0$$

$$INV_t^* = z_t' \gamma + \nu_t \qquad \text{if } INV_t^* \leq 0$$

Coherency is guaranteed if $1 - \gamma_2 > 0$ or $\gamma_2 < 1$. For computational ease, we define a new latent variable INV_t^{**} such that

$$INV_t^{**} = INV_t^* = INV_t \qquad \text{if } INV_t^* > 0$$

$$INV_t^{**} = INV_t^* \,/\, (1 - \gamma_2) \qquad \text{if } INV_t^* \leq 0$$

We then have

$$INV_t^{**} = z_t' \, \gamma^* + \nu_t^* \quad \text{where } INV_t = INV_t^{**} \text{ if } INV_t^{**} > 0 \qquad (6.11)$$
$$= 0 \qquad \text{otherwise}$$

with $\gamma^* = \gamma/(1 - \gamma_2)$ and $\nu_t^* = \nu_t/(1 - \gamma_2)$. Equation (6.11) can be estimated with standard Tobit ML procedures. The results are reported in Table 6.1. This provides the reduced-form estimates for γ^* and $\sigma^2_{\nu^*}$.

Now, we return to (6.9). Assuming joint normality of ϵ_t and ν_t^* (or ν_t), with covariance $\sigma_{\epsilon\nu^*}$, it holds that

$$E\left(\epsilon_t \mid (S_t^P - S_t^{MA}),\ (S_{t-1}^U - S_{t-1}^P),\ INV_t\right) = \sigma_{\epsilon\nu^*} \,.\, E\left(\nu_t^* \mid INV_t,\ z_t\right)$$

where $\sigma_{\epsilon\nu^*} = 0 \Leftrightarrow \beta_2 = 0$. Apart from $\sigma_{\epsilon\nu^*}$ this term can be estimated consistently after replacing the unknown parameters in E $(\epsilon_t^* \mid INV_t, z_t)$ by their estimates from (6.11). The resulting estimate is known as the generalized residual in (6.11).[8] It can be shown that

$$E\left(\nu_t^* \mid INV_t\ ,\ z_t\right) = \nu_t^* = INV_t - z_t' \, \gamma^* \qquad \text{if } INV_t^{**} > 0$$
$$= -\,\sigma_{\nu^*} \frac{\varphi\,(z_t'\gamma^*/\sigma_{\nu^*})}{\Phi\,(z_t'\gamma^*/\sigma_{\nu^*})} \qquad \text{if } INV_t^{**} \leq 0$$

where $\varphi(.)$ and $\Phi(\cdot)$ are the standard normal density function and cumulative density function (distribution function), respectively. Finally, we rewrite (6.9) as

$$(S_t^U - S_t^P) = \alpha_0 + \alpha_1\, INV_t + \alpha_2\,(S_{t-1}^U - S_{t-1}^P) +$$
$$+ \sigma_{\epsilon\nu^*} \,.\, E\left(\nu_t^* \mid INV_t\ ,\ z_t\right) + \epsilon_t^* \qquad (6.12)$$

where, by construction, ϵ_t^* is orthogonal with each of the explanatory variables. After replacing the unknown parameters in $E\,(\nu_t^* \mid INV_t, z_t)$ by their estimates, (6.12) can be estimated by OLS providing a consistent

Table 6.1 ML estimation results for an auxiliary Tobit model

$$INV_t^{**} = \gamma_1^* + \gamma_2^* (S_t^P - S_t^{MA}) + \gamma_3^* (S_{t-1}^U - S_{t-1}^P)$$

Period	γ_1^*	γ_2^*	γ_3^*	Log L	Obs.
Bundesbank intervention in the DM/$ market					
87(2)—88(4)	—525.45	—234.21	—76.17	—295.53	297
	(—5.85)	(—5.36)	(—0.82)		
88(5)—89(10)	204.34	—86.19	—50.18	—984.49	380
	(—6.59)	(—3.88)	(—0.90)		
Federal Reserve intervention in DM/$ market					
87(2)—88(4)	—337.59	—137.11	—76.20	—262.22	300
	(—5.82)	(—4.89)	(—1.31)		
88(5)—89(10)	154.75	—57.33	—25.71	—829.07	373
	(6.46)	(—3.89)	(—0.80)		
Federal Reserve intervention in yen/$ market					
87(2)—88(1)	—302.42	—126.79	—85.10	—364.37	236
	(—6.09)	(—5.45)	(—1.57)		
89(1)—89(10)	130.02	—43.20	22.55	—510.87	207
	(4.41)	(—2.90)	(0.60)		

Note: *t*-statistics in parentheses.

estimator for $\sigma_{\epsilon\nu^*}$. An asymptotically valid test for H_0: $\sigma_{\epsilon\nu^*} = 0$ ($\beta_2 = 0$) is the usual *t*-test.

The results of estimating equation (6.12) are depicted in Table 6.2. The null hypothesis H_0: $\sigma_{\epsilon\nu^*} = 0$, which is equivalent to the null hypothesis of no endogeneity in the volume of daily Bundesbank and Federal Reserve intervention, $\beta_2 = 0$, is not rejected in any of the eleven regressions. Therefore, this study proceeds by assuming that equation (6.6) and hence equations (6.2)—(6.4) can be estimated consistently with OLS.

Table 6.2 Testing for endogeneity of Bundesbank and Federal Reserve interventions; OLS estimation results.

$$s_t^U - s_t^P = \alpha_0 + \alpha_1 \, INV_t + \alpha_2 \, (s_{t-1}^U - s_{t-1}^P) + \sigma_{\epsilon v} . \, E\left(v_t^* \mid INV_t, z_t\right)$$

Period	α_0	α_1	α_2	$\sigma_{\epsilon v}$*	$\bar{R}^2$	DW	Obs.
Bundesbank intervention in the DM/$ market							
87(2)—	0.045	—64.0	0.031	0.00016	0.017	1.99	297
88(4)	(1.87)	(—2.50)	(0.49)	(1.13)			
88(5)—	0.039	14.0	0.030	7.53	—.003	2.00	380
89(10)	(1.63)	(1.04)	(0.56)	(0.89)			
Federal Reserve intervention in the DM/$ market							
87(2)—	0.013	—120.0	—0.090	0.00040	0.026	1.91	300
88(4)	(0.58)	(—2.97)	(—1.52)	(0.75)			
88(5)—	—0.026	—5.4	—0.058	—37.0	0.005	1.98	373
89(10)	(—0.60)	(—0.08)	(—1.09)	(—0.72)			
Federal Reserve intervention in the yen/$ market							
87(2)—	0.0025	—48.0	—0.107	—0.015	0.004	2.00	236
88(1)	(0.08)	(—1.38)	(—1.53)	(—0.87)			
89(1)—	0.020	116.0	0.031	—4.04	0.007	2.03	207
89(10)	(0.29)	(1.33)	(0.43)	(—0.53)			

Notes: See Table 4.1. The coefficient on INV_t (α_1) and its corresponding standard error are multiplied by 100,000 for readability.

6.5 ESTIMATING THE EFFECT OF INTERVENTION ON THE LEVEL OF THE DM/$ RATE

The results of the test procedure implemented in the previous section indicate that the volume of intervention can be regarded as an exogenous variable in equation (6.6). Therefore, equations (6.2)—(6.4) can be estimated consistently with OLS. This provides us with a direct test of the effect of intervention on the level of the exchange rate. Estimation results are shown in Table 6.3. The first four regression results refer to the effectiveness of Bundesbank interventions in the Deutsche Mark/US dollar exchange market.[9] The dependent variable in the first four regressions is the intradaily percentage change in the DM/$ rate in the Frankfurt market. During the first regression period the Bundesbank carried out purchases of US dollars. The three other periods were characterized by sales of US dollars. The constant (α_0) is positive in all four subsamples, though not significant. This reflects an appreciation of the US dollar *vis-à-vis* the Deutsche Mark in the Frankfurt market. However, during the first subsample, the US dollar lost ground overall. Probably, the major part of the overall dollar depreciation in the months after the stockmarket crash of October 1987 took place during the non-European segment of the DM/$ exchange market (that is, while the Frankfurt exchange was closed). The negative value of the constant in the first regression for Federal Reserve intervention lends some support to this. The dependent variable in the first four regressions for Federal Reserve intervention is the intradaily percentage change in the DM/$ rate in the New York market. Now compare the values of the constant in the regressions for the three periods which were characterized by sales of US dollars. It appears that the waves of dollar appreciation these periods have in common were mainly concentrated in the European segment of the foreign exchange market. This is the segment during which most German 'news' is released (e.g. monetary policy announcements made after the bi-weekly meetings of the Central Bank Council of the Bundesbank). The estimation results suggest that the rise in the DM/$ rate during these periods is a result of weakness of the Deutsche Mark rather than strength of the US dollar. More importantly, the estimation results in Table 6.3 indicate that the interventions conducted by the Bundesbank and the Federal Reserve on the whole did not systematically affect the level of the DM/$ rate across the four subsamples. The coefficient for Bundesbank intervention (α_1) in the fourth sample is correctly signed and significant at a mere 20 per cent level in a two-sided test. It suggests that during the period August 1989—October 1989 a sale of US dollars worth DM100 million on average led to a lowering of the DM/$ rate by 0.096 per cent.

The three regressions at the bottom of Table 6.3 refer to the effectiveness of Federal Reserve interventions in the Japanese yen/US dollar exchange market. The dependent variable in these regressions is the intradaily percentage change in the yen/$ rate in the New York market. During the first and second regression period the Federal Reserve carried out purchases of US dollars. The third period is characterized by sales of US dollars. The estimation results suggest that sales of US dollars carried out by the Federal Reserve during the period

Table 6.3 The effect of Bundesbank and Federal Reserve interventions on the level of the DM/\$ rate and the ¥/\$ rate; OLS estimation results

$$100\ (s_t^U - s_t^P) = \alpha_0 + \alpha_1\ INV_t + \alpha_2\ (100\ (s_{t-1}^U - s_{t-1}^P))$$

Period	α_0	α_1	α_2	$\bar{R}^2$	DW	Obs.
Bundesbank intervention in the DM/\$ market						
87(9)—88(1)	0.073	—73.0	0.038	0.018	1.98	105
	(1.38)	(—1.86)	(0.38)			
88(6)—88(9)	0.102	10.9	—0.055	—0.016	1.97	86
	(1.72)	(0.56)	(—0.50)			
88(12)—89(3)	0.060	33.0	0.043	—0.017	1.99	84
	(1.40)	(0.79)	(0.37)			
89(8)—89(10)	0.073	96.0	—0.104	0.008	2.05	66
	(1.13)	(1.30)	(—0.84)			
Federal Reserve intervention in the DM/\$ market						
87(10)—88(1)	—0.041	—15.0	—0.086	—0.018	2.00	81
	(—0.70)	(—0.20)	(—0.75)			
88(6)—88(9)	0.015	—80.0	—0.103	0.013	1.96	86
	(0.27)	(—1.73)	(—0.89)			
89(1)—89(6)	0.00075	—24.0	—0.158	0.011	1.96	125
	(0.01)	(—0.54)	(—1.77)			
89(8)—89(10)	0.0024	—62.0	0.095	—0.016	1.97	62
	(0.03)	(—0.54)	(0.72)			

(Table 6.3 continued)

$$100\ (s_t^U - s_t^P) = \alpha_0 + \alpha_1\ INV_t + \alpha_2\ (100\ (s_{t-1}^U - s_{t-1}^P))$$

Period	α_0	α_1	α_2	$\bar{R}^2$	DW	Obs.
Federal Reserve intervention in the Yen/$ market						
87(3)—87(5)	—0.0043	—45.7	—0.1619	0.005	1.97	64
	(—0.06)	(—1.05)	(—1.27)			
87(10)—88(1)	0.0034	—54.4	—0.098	—0.009	1.98	102
	(0.07)	(—0.51)	(—0.98)			
89(4)—89(10)	0.034	66.3	0.048	0.005	2.03	146
	(0.59)	(1.56)	(0.58)			

Notes: See Table 6.2.

April 1989—October 1989 on average led to a fall in the value of the US dollar *vis-à-vis* the Japanese yen. The coefficient for Federal Reserve intervention in the bottom row is correctly signed and significant at a 12 per cent level in a two-sided test. It implies that during the period April 1989—October 1989 a sale of US$100 million against Japanese yen on average led to a lowering of the yen/$ rate by 0.066 per cent.

We also carried out an event study of the effectiveness of daily Bundesbank and Federal Reserve interventions. Under the assumption that the relevant opening spot rate (S_t^P) incorporates all information available at the time of collection and that interventions are unpredictable, the event study takes the form of estimating equations (6.2)—(6.4) with the zero-intervention observations left out of the samples. The following result was found for Bundesbank intervention during the fourth period, from August 1989 to October 1989:

$$100\ (\log SFR_t^{16.30} - \log SFR_t^{8.30}) = \underset{(2.42)}{0.422} + \underset{(2.41)}{0.00235}\ INV_t^{DBB}$$

$$\bar{R}^2 = 0.2430 \qquad DW = 1.556 \qquad Obs. = 16$$

As before, *t*-statistics are in parentheses. During the period considered, sales of US dollars conducted by the Bundesbank were accompanied by, and perhaps even caused, a major shift of the market sentiment in favour of a stronger Deutsche Mark. A similar regression on all nonzero-intervention observations over the whole sample period, from September 1987 to October 1989, does not obtain a correctly signed and significant intervention coefficient for either of the central banks. This confirms that there is no time-invariant one-to-one relationship with interventions causing exchange rate movements; much seems to depend on the strength of the market sentiment and the ability of central bankers to 'read' it.

6.6 CONCLUSIONS

It is a fact of observation that central banks enter the foreign exchange market when there are prolonged exchange rate movements in one direction. Estimates of intervention reaction functions presented in Chapters 4 and 5 confirm this. This chapter makes two contributions to understanding and testing the effectiveness of central bank interventions. Firstly, this study contains an in-depth analysis of the simultaneity problem between intradaily exchange rates and daily interventions. A test procedure proposed by Vella (1993) is implemented to determine that in the reduced forms estimated in this chapter daily interventions can be treated as an exogenous variable. Secondly, the direct effect of intervention on the level of the exchange rate is estimated.

The estimation results presented in this chapter cover the post-Louvre period February 23, 1987 to October 31, 1989. They indicate that, in general, interventions conducted by the Bundesbank and the Federal Reserve System were not successful at systematically reversing unwanted movements in the DM/$ and the ¥/$ exchange rates. This contradicts the findings of Dominguez and Frankel (1993a,b). However, the estimation results in the latter studies are subject to simultaneity bias and/or involve testing the effectiveness of interventions indirectly through a risk premium.

Of course, the conclusion regarding the general ineffectiveness of intervention does not rule out the possibility that private exchange market participants may sometimes be caught off balance by the news of central banks entering the market. What it does imply is that there is no time-invariant one-to-one relationship with interventions causing exchange rate movements. This confirms the intuition of many private exchange market participants and central bankers who manage the Foreign Exchange Trading Desk.[10]

NOTES

1. This chapter is based on Almekinders and Eijffinger (1994c).
2. It is commonly assumed that intraday exchange rate movements are caused primarily by short-term capital flows. In an efficient market investors balance their portfolios at every moment. A change in the interest rate differential will lead to imbalances. This immediately induces an adjustment process in the highly efficient money and foreign exchange markets. A relative rise in the DM interest rate will bring about a demand surplus for financial assets denominated in DM. Given the supply of DM assets in the short run, portfolio equilibrium will be restored by a fall in the exchange value of one U.S. dollar in terms of DM. Unfortunately, intradaily interest rate data matching the opening and closing of the Frankfurt and New York exchanges were not available. Goodhart (1988) interviewed numerous interbank foreign exchange traders. He found that an 'open position is seen generally as a pure currency play with little attention normally being given to interest rates' (Goodhart 1988, p. 457). Estimation results on daily data in Goodhart (1988) indicate that omitting from equation (6.1) the variable capturing the change in the short-term interest differential will not detract from its relevance. Goodhart concludes that interest rate changes, which he assumes to be mainly unanticipated, 'explain effectively none of the exchange rate fluctuations' (Goodhart 1988, p. 441). The same result emerges from empirical investigations in Eijffinger and Gruijters (1992).
3. Loopesko (1984) found a high degree of contemporaneous correlation between daily exchange rates and daily interventions.
4. The intervention reaction functions estimated in Chapters 4 and 5 contain the conditional variance of day t's return in the DM/$ market as an additional explanatory variable. Estimation results for GARCH models of daily exchange rate returns were used to generate time series for the conditional variance. In the present chapter, such a two-step procedure can lead to incorrect results. Such two-step estimators sometimes lead to inconsistent point estimates in the second-step equation, and often to incorrect standard errors. More importantly, this may invalidate the test procedure implemented in the next section of this chapter, which is based on normally and independently distributed errors.
5. Note that in Chapters 4 and 5 the term $\beta_2\ (S_t^U - S_t^P)$ was omitted from the intervention reaction function to rule out a possible simultaneity bias in the estimation results.
6. Periods of prolonged interventions in one direction are selected to rule out the possibility that 'negative' desired interventions are simply observed interventions in the opposite direction (i.e. selling instead of buying and vice versa).
7. However, the ML estimation will only provide meaningful results when equations (6.5) and (6.6) are coherent, i.e. when they can be solved uniquely for INV_t and $(S_t^U - S_t^P)$, given $(S_t^P - S_t^{MA})$, ϵ_t and μ_t.
8. If equation (6.10) is a linear regression model, it corresponds to the usual residual.
9. A description of the main factors determining the course of the DM/$ rate in each of the four regression periods was given in Chapter 4.
10. Gleske, a former executive director of the Deutsche Bundesbank responsible for intervention operations states that 'under certain circumstances, only small interventions may suffice to curb or even reverse an unwanted movement in the exchange rate. In other cases even large interventions may result in the opposite effect; when market participants are convinced of the strength of an underlying trend' (Gleske 1982, p. 265, my translation).

7. A Positive Theory of Intervention

7.1 INTRODUCTION

Chapter 2 analysed the channels of influence of intervention. It was established that, at least in the framework of structural exchange rate models, the scope for sterilized intervention is rather limited. Yet, it is a fact of observation that central banks do enter the market for foreign exchange in case of strains. Empirical evidence provided in Chapters 4 and 5 indicates that both the Bundesbank and the Federal Reserve System conduct their foreign exchange operations consistently. However, estimation results provided in Chapter 6 do not suggest that interventions conducted by the Bundesbank and the Federal Reserve were successful at systematically reversing unwanted movements in the DM/$ rate. This seeming contradiction raises the question: why do central banks continue to intervene? The aim of this chapter is to provide a positive theory of central bank intervention. This involves investigating the motives and constraints facing central banks when they decide to engage in foreign exchange intervention.

There is a large literature on optimal exchange rate management (e.g., Boyer 1978, Roper and Turnovsky 1980 and Glick and Hutchison 1989). The analysis in these studies is cast in terms of deriving the exchange rate regime which minimizes the variance of output around its mean level. In other words, these studies are concerned with computing the optimal degree of unsterilized intervention in response to various shocks impinging on the domestic economy. However, it is well known that the central banks in the major industrialized countries routinely neutralize the money-market effect of interventions. The limited effectiveness of pure interventions imposes a serious constraint on the intervention behaviour of the central bank. Moreover, it seems to have important implications for the objectives of central bank intervention. Stabilizing output is out of the question. Even stabilizing the exchange rate may turn out to be a 'mission impossible'.

Central bank intervention has mostly been investigated as a game against nature. This implies that private exchange market participants are assumed to regard the central bank as 'just another exchange market participant'. Consequently, private market participants do not engage in 'central bank watching'. Furthermore, and what is more important, they do not base foreign exchange trading on the anticipation of central bank intervention. Section 7.2 highlights the conventional approach to modelling central bank intervention. In a flow model of the exchange rate three categories of currency flows are distinguished: currency flows originating from current account transactions, currency flows associated with capital account transactions and currency flows brought about directly by the central bank. These three categories are put in one comprehensive analytical framework to investigate whether and how the central bank is able to attain its objectives in the field of exchange rate policy. The objectives of the central bank are embodied in a simple loss function. It reflects the hypothesis that the domestic central bank wishes to limit deviations of the current exchange rate from a target level. Section 7.3 recognizes the bad performance of structural models of exchange rate determination in empirical tests. It implements the 'finance approach' to the exchange rate. The random-walk model of the exchange rate is amended to include the effect of sterilized central bank intervention. Intervention reaction functions are derived for various specifications of the central bank loss function and for various schemes of expectations-formation among private exchange market participants. It was noted before that the limited effectiveness of sterilized intervention imposes a severe constraint on intervention behaviour. Obviously, there may be other constraints as well. Costs of intervention are introduced in the loss function of the central bank to make it somewhat more realistic in the sense that it better reflects the actual motives and constraints facing central banks. There may be bureacratic or decision costs involved in conducting intervention. Furthermore, the central bank incurs losses when purchases (sales) of foreign currency turn out to be unsuccessful at preventing the domestic currency from appreciating (depreciating).

To influence exchange rate movements interventions basically have to alter the balance of supply and demand for foreign exchange. However, average central bank transactions in foreign exchange are very small compared to the daily turnover on the global foreign exchange market. Furthermore, due to the sterilization of the money-market effect, the interventions, in essence, involve nothing but a shift in the currency composition of private investment portfolios. In Section 2.3.4 it was shown how sterilized interventions may exert an effect on the exchange rate through the portfolio balance channel by causing an imbalance in investors' portfolios. Bhattacharya and Weller (1992, p. 4) note that 'it is implausible to suppose that the impact of such tiny changes in the worldwide asset mix would have a significant effect on exchange rates'. Empirical studies into the effectiveness of central bank intervention surveyed in Chapter 3 and the estimation results reported in Chapter 6 lend support to this. According to Bhattacharya and Weller, the introduction of strategic behaviour by central banks can alter the scope for intervention dramatically. Section 7.4 investigates the motives and constraints facing central banks when there is strategic interaction between the central bank on the one hand and private exchange market participants on the other hand. It is a fact of observation that private exchange market participants are eager to detect any information related to official operations in foreign currency. Central bankers, in turn, know that their actions are monitored very carefully. Therefore, it seems to make sense to abandon the implicit assumption of Sections 7.2 and 7.3 that the central bank is regarded by private exchange market participants as 'just another exchange market participant'.

The order of events in the resulting exchange rate policy game is as follows. Each time period, individual private exchange market participants interpret the 'news' and rumours in the foreign exchange market and react to it. The interplay among the diverse group of private exchange market participants leads to a shock to the exchange rate. This shock is observed both by private currency traders and the central bank. The central bank wants to counteract the shock to the exchange rate. However, it is aware of the relative negligibility of typical intervention efforts compared to the average daily turnover in the foreign exchange market. In order to maximize the effect of interventions carried out to counteract speculative shocks to the demand for foreign exchange, the central bank will try to catch private speculators off balance by means of surprise interventions. Under symmetric information private exchange market participants know that the central bank will be tempted to offset the initial shock to the exchange rate by carrying out a larger-than-expected intervention, so they purposely set the expected volume of intervention high. At the same time, the central bank weighs the benefits and the costs of intervention, and only finds it optimal to carry out the volume of intervention expected by the private sector. The non-cooperative equilibrium of the exchange rate policy game has an inefficient 'intervention bias'. It is inefficient to carry out a nonzero equilibrium amount of intervention because the costs involved are not offset by any benefits. The nonzero amount of intervention is fully anticipated by the private sector. Therefore, it is not successful at limiting the impact of the initial shock to the exchange rate. This is the case if the central bank systematically tries to counteract realized shocks to the exchange rate and if the private sector has full information about the shape of the policy loss function which underlies the intervention behaviour of the central bank. Section 7.4.8 investigates the sensitivity of the equilibrium volume of intervention to changes in the central bank's aversion to non-fundamental exchange rate changes. Furthermore, two propositions are derived with regard to the link between central bank independence and the magnitude and the variability of the volume of intervention. Section 7.4.9 investigates whether these propositions are supported by cross-country evidence. Section 7.5 analyses three extensions of the basic exchange rate policy game against rational speculators. First, attention is paid to a dynamic extension of the game. Second, returning to the static game, the implications of unequal status of the players are studied. Third, allowance is made for the central bank to have asymmetric information about shifts in its own preferences. Section 7.6 concludes the discussion.

7.2 CENTRAL BANK INTERVENTION AS A DETERMINISTIC GAME AGAINST NATURE

7.2.1 Introduction

Central bank foreign exchange market intervention has mostly been investigated as a game against nature. Accordingly, as a first step the central bank lets private exchange market participants engage in position-taking in foreign currency. Foreign exchange market intervention comes to the fore only when the resulting movements in the exchange rate are out of line with what the central bank regards as acceptable. For instance, suppose private speculators expect an immediate depreciation of the domestic currency. Unless the interest rate differential in favour of investments denominated in domestic currency is sufficiently high to compensate investors for the expected depreciation, this will induce them to sell domestic currency in return for foreign currency. The central bank may try to counteract the downward pressure on the value of the domestic currency and do exactly the opposite of what the private sector does with respect to position-taking in foreign exchange.

Modellng central bank intervention as a game against nature implies that exchange market participants are assumed to regard the central bank as 'just another exchange market participant'. Consequently, there is no strategic interaction among private and official market participants.

7.2.2 The exchange rate in a flow model

The determination of the exchange rate can be modelled by implementing a simplified flow market interpretation as in Neumann (1984) and Black

(1985).[1] Equation (7.1) gives the market-clearing condition of the foreign exchange market in a two-country model:

$$INV_t = CA_t + \Delta K_t \tag{7.1}$$

where the left-hand side describes the net supply of domestic currency, the right-hand side the net demand for domestic currency. INV_t denotes the volume of central bank purchases of foreign currency (= sales of domestic currency) in period t. For simplicity it is assumed that only the domestic central bank engages in operations in foreign currency. The first part of the net flow demand for domestic currency in the foreign exchange market results from current account transactions between the two countries. The current account surplus of the domestic economy (CA_t) can for instance be thought of as depending on lagged values of the real exchange rate. In the present context it needs no further specification. The second part of the net flow demand for domestic currency in the foreign exchange market results from capital account transactions. It is assumed that current account deficits of the domestic country are financed by 'exporting' domestic currency-denominated financial assets only. An expression for the net flow demand for domestic currency through the capital account of the balance of payments (ΔK_t) can be derived from the postulated behaviour of a representative foreign investor. Suppose the representative foreign investor trades off the expected rate of return in foreign currency on assets denominated in domestic currency ($i - (E_t s_{t+1} - s_t)$) against the expected rate of return on assets denominated in foreign currency (i_t^*), where, as before, s_t is defined as the (log of the) domestic currency price of one unit of foreign exchange, i_t and i_t^* are the one-period interest rates on assets denominated in domestic and foreign currency, respectively. The *ex post* profit in foreign currency, net of opportunity costs, of holding K_t assets denominated in domestic currency is[2]

$$\Pi_{t+1} = K_t\,(i_t - i_t^* - (s_{t+1} - s_t)) \tag{7.2}$$

In speculative dynamics models (Stein (1987), De Long et al. (1990)) the representative speculator is commonly assumed to have a constant absolute risk-aversion utility function,

$$U = -e^{-\gamma\,\Pi} \tag{7.3}$$

where γ is the coefficient of absolute risk aversion and Π denotes the representative investor's profits. According to De Long et al. (1990, p.

708), when the returns to holding assets denominated in foreign currency are normally distributed, maximizing the expected value of (7.3) is equivalent to maximizing

$$E(U) = E_t\Pi_{t+1} - \frac{\gamma}{2} Var_t\Pi_{t+1} \tag{7.4}$$

where $E_t\Pi_{t+1}$ and $Var_t\Pi_{t+1}$ are the conditional expected profit in foreign currency of holding assets denominated in domestic currency and its variance given information available at time t. Therefore, we have

$$E_t\Pi_{t+1} = K_t\ (i_t - i_t^* - (E_t s_{t+1} - s_t)) \tag{7.5}$$

$$Var_t\Pi_{t+1} = E_t\ [K_t\ ((i_t - i_t^* - (s_{t+1} - s_t)) - (i_t - i_t^* - (E_t s_{t+1} - s_t))]^2$$

$$= E_t\ [K_t\ (-(s_{t+1} - E_t s_{t+1}))]^2 = K_t^2\ Var_t s_{t+1} \tag{7.6}$$

where $Var_t s_{t+1}$ is the conditional variance of the exchange rate in the next period. Substituting the expressions in (7.5) and (7.6) into equation (7.4) and differentiating with respect to K_t yields the following solution for the representative investor's optimum position in assets denominated in domestic currency

$$K_t^* = \frac{(i_t - i_t^*) - (E_t s_{t+1} - s_t)}{\gamma\ Var_t s_{t+1}} \tag{7.7}$$

Accordingly, the representative investor, *ceteris paribus*, invests more in assets denominated in domestic currency when the expected rate of return in foreign currency on assets denominated in domestic currency (i — $(E_t s_{t+1}$ — $s_t)$) becomes larger than the expected rate of return on assets denominated in foreign currency (i^*), when he becomes less averse to risk, i.e. when γ declines, and when the conditional variance of the next-period exchange rate, $Var_t\ s_{t+1}$, is smaller.

Expectations regarding the mean and variance of the exchange rate are determined outside the simple model presented here. As a consequence, both $E_t\ s_{t+1}$ and $Var_t\ s_{t+1}$ do not depend on the volume of intervention conducted by the central bank. The implications of this will be discussed below. For simplicity it will be assumed that the conditional variance of the exchange rate is time-independent, i.e. $Var_t\ s_{t+1} = Var_{t-1}\ s_t = Var\ s_t$.

The crucial characteristic of the flow model is that the exchange rate adjusts instantaneously so as to equilibrate demand and supply for domestic currency at any point in time. The mechanics of this can be seen after substituting equation (7.7) into the market-clearing condition in equation (7.1). Under freely floating exchange rates, i.e. when the central bank abstains from intervention ($INV_t = 0$), the resulting equation can be written:

$$0 = CA_t + \frac{\Delta\left[(i_t - i_t^*) - (E_t\, s_{t+1} - s_t)\right]}{\gamma\ Var\ s_t} \tag{7.8}$$

Suppose the domestic economy ran a current account deficit in previous periods and that, at the end of period t—1, it is a net debtor to the foreign country. In period t the current account of the domestic country turns into surplus due to recent rises in the real exchange rate. This causes an incipient excess flow demand for domestic currency. As a result, the nominal exchange rate s_t falls. The appreciation of domestic currency detracts, *ceteris paribus*, from the attractiveness of investments denominated in domestic currency. For, given next-period's expected exchange rate ($E_t\, s_{t+1}$), the actual fall in the exchange rate enlarges the expected depreciation of the domestic currency. As this is not compensated by a larger interest differential in favour of investments denominated in domestic currency, foreign investors will on net dispose of some of their investments denominated in domestic currency. At the new exchange rate s_t the resulting excess flow supply of domestic currency flowing through the capital account of the balance of payments is equal to the excess flow demand for domestic currency caused by the current account surplus.

7.2.3 The behaviour of the central bank

Net flows of domestic currency through the current account depend on price differentials between foreign and domestic goods and services. Net flows of domestic currency through the capital account depend on return differentials on assets denominated in different currencies. It should be clear from the market-clearing condition in equation (7.1) that there may be a third category of nonzero net flows of domestic currency through the balance of payments. This third category is at the discretion of the central bank. In practice, all central banks have a common short-term objective of 'countering disorderly exchange market conditions'. It is part of their commitment to promote a stable exchange rate system in accordance with the Articles of Agreement of the IMF as amended in 1992. Therefore, it is rather straightforward to make a behavioural assumption for the central bank.

Assume a single-period loss function of the central bank which is quadratic in the deviation of the current exchange rate (s_t) from an exogenous target level (s_t^T). It thus reflects the hypothesis that the domestic central bank wishes to limit deviations from this target level irrespective of sign, and that the loss increases more than proportional with increases in the deviation:

$$L_t^{CB} = (s_t - s_t^T)^2 \tag{7.9}$$

To capture intervention carried out on account of a 'leaning against the wind' policy, the target level for the exchange rate can be thought of as representing past levels of the exchange rate. This follows immediately from the definition of smoothing exchange rate fluctuations: whether or not the exchange rate was considered to be at a desirable level in the previous period(s), deviations from this target level will be countered.

In accordance with the essentials of the flow model of the exchange rate the volume of purchases of foreign currency (INV_t) is the only instrument the central bank can dispose of freely to limit deviations of the actual exchange rate from the target level. Moreover, in line with the assumption that the central bank is playing a game against nature the volume of intervention only has a bearing on the excess supply or demand in the foreign exchange market. The private sector regards the central bank as 'just another exchange market participant'. Consequently, an indirect effect of interventions on the current exchange rate through an effect of INV_t on next-period's expected exchange rate ($E_t\, s_{t+1}$) or the conditional variance of the exchange rate ($Var_t\, s_{t+1}$) is ruled out.

An intervention reaction function can be obtained by minimizing the loss function (7.9) with respect to the volume of intervention INV_t. Solving for INV_t after taking account of the constraints implied by the exchange rate equation in (7.1) and the expression for the optimal position in assets denominated in domestic currency in (7.7) gives[3]

$$INV_t = CA_t + \frac{1}{\gamma\ Var\ s_t}\Big(\Delta\ RP_t - (s_t - s_t^T)\Big) \tag{7.10}$$

The reaction function in equation (7.10) implies that there are three potential reasons for intervention: one *direct* reason and two *indirect* ones. The domestic central bank supplies amounts of domestic currency to the foreign exchange market ($INV_t > 0$) when the current exchange rate is below the target value ($s_t < s_t^T$). While it concerns monitoring of the actual exchange rate I would refer to this as a direct reason for intervention. The central bank detects the two other reasons for intervention by monitoring exchange market pressure which will eventually result in revisions of the actual exchange rate away from the target level. Therefore, these could be referred to as *indirect* reasons for intervention. Firstly, the domestic central bank sells domestic currency ($INV_t > 0$) in proportion to the current account surplus of the domestic economy ($CA_t > 0$). Obviously, the current account surplus induces an excess demand for domestic currency which is bound to drive the actual exchange rate below the target exchange rate. Secondly, equation (7.10) implies that the domestic central bank sells domestic currency to counteract the effect on the exchange rate of an increased demand for assets denominated in domestic currency. Official sales of domestic currency ($INV_t > 0$) are carried out when the expected risk premium on assets denominated in domestic currency becomes larger than the minimum risk premium private investors require for investing in domestic currency.

7.2.4 Evaluation

Following Neumann (1984) a simplified flow market interpretation of exchange rate determination is used to track the determinants of exchange rate movements. The model is deterministic. This implies that there are no unexpected events impinging on the foreign exchange market. It is assumed that the central bank wishes to keep movements in the exchange rate perfectly under control. Additionally, and perhaps more controversially, it is also assumed that the central bank is *able* to keep movements in the exchange rate perfectly under control, i.e. it is assumed that the central bank has sufficient resources to counter movements in exchange rates brought about by private currency flows. Given these assumptions it is hardly surprising that the central bank turns out to be able to attain its objective of keeping the exchange rate on the target level. The value of the central bank's loss function in the present deterministic game against nature is equal to zero, $L_t^{CB} = (s_t - s_t^T)^2 = 0$. This follows directly from solving (7.1) and (7.10) for the exchange rate and substituting the resulting relationship into the loss function (7.9).

7.3 CENTRAL BANK INTERVENTION AS A STOCHASTIC GAME AGAINST NATURE

7.3.1 Introduction

The merit of the flow approach to the foreign exchange market is that it discerns some fundamental driving forces behind movements in the external value of a currency. The model in the previous section distinguished three categories of currency flows: currency flows originating from current account transactions, currency flows associated with capital account transactions and currency flows brought about directly by the central bank. These three categories were put in one comprehensive analytical framework. However, in practice the lion's share of the daily turnover on the foreign exchange market is made up of speculative capital flows. In Section 1.2 it was established that the proportion of international currency flows which are directly associated with international trade in goods and services is very tiny. The proportion of international currency flows which are directly brought about by the central bank is fairly negligible. Moreover, periods with (sometimes prolonged) interventions are alternated by longer periods with no intervention. Putting the three categories of foreign currency flows in one comprehensive analytical framework is bound to lead to 'insights' which are way out of line with what one observes in reality. For instance, the reaction function in (7.10) implies that the domestic central bank buys foreign currency aimed at withstanding downward pressure on the exchange rate caused by an expected return differential in favour of investments denominated in domestic currency. This is not what one sees in practice. Rather, central bank interventions are of an order of magnitude smaller than private capital flows. In any case, it is well known that the flow model, like other structural models of the exchange rate, performs poorly in empirical tests.

The failure of structural exchange rate models in empirical tests has led many economists to adopt new research strategies in exploring the field of exchange rate economics. Within a short time an extensive literature has developed which aims to describe the mere statistical properties of the time series of exchange rates (for a survey see De Vries 1994). In this literature short-term exchange rate returns are thought of as resulting from the interaction among the various sorts of exchange market participants and their interpretation of, and reaction to the 'news' which hits the market almost continuously. However, the behaviour of the different groups of exchange market participants and the interaction among them is mostly left unspecified ('black box').

In this section the popular random-walk model of the exchange rate is amended to allow for an effect of intervention. To influence currency movements, interventions basically have to alter the balance of supply and demand for foreign exchange. However, typical intervention efforts are very tiny compared to the daily turnover on foreign exchange markets. Furthermore, in practice their money-market effect is routinely neutralized. In Section 2.3.4 it was shown how sterilized interventions may eventually exert an effect on the exchange rate through the portfolio balance channel by causing an imbalance in investors' portfolios.

In the course of this section it will be seen that the unrealistic features of the reaction function derived in the previous section do not disappear by postulating a different exchange rate model. The reaction functions still imply that the central bank, when faced with shocks to the exchange rate, unconditionally engages in intervention to mitigate the effect of these shocks. In Section 7.3.6 it is assumed that there are costs involved in intervening. This forces the central bank to weigh the benefits and costs of intervention when confronted with speculative shocks to the exchange rate.

7.3.2 The random-walk model of the exchange rate amended to include the effect of intervention

Consider the following stochastic process for the exchange rate, s_t

$$s_t = a + \delta_0 \, s_{t-1} + \epsilon_t, \qquad \epsilon_t | \Omega_{t-1} \sim N\,(0, \sigma_\epsilon^2) \tag{7.11}$$

where a and δ_0 are a constant term and a coefficient, respectively; ϵ_t is a stochastic disturbance term. Conditional on information available at time t—1, denoted by Ω_{t-1}, the disturbance term is normally distributed with mean zero and constant variance σ_ϵ^2.[4] One of the early insights of what I would call the 'finance approach' to the exchange rate is that short-term exchange rates contain a unit root.[5] This means that the null hypothesis that the coefficient δ_0 is equal to one can not be rejected in a t-test (see, e.g. Meese and Singleton 1982 and Baillie and Bollerslev 1989).

After taking account of the unit root in the time series of the exchange rate and after amending the model in (7.11) to include the effect of central bank interventions it can be written:

$$\Delta \, s_t = a + \delta^V \, INV_t + \epsilon_t, \qquad \epsilon_t | \Omega_{t-1} \sim N\,(0, \sigma_\epsilon^2) \tag{7.12}$$

where a is a 'drift'-term which denotes a constant rate of depreciation of the domestic currency *vis-à-vis* foreign currencies. This constant and therefore perfectly predictable change in the value of domestic currency may be due to the underlying weakness of the domestic economy measured by, for instance, the macroeconomic fundamentals. It may also be caused by self-fulfilling depreciation expectations among currency speculators which are detached from economic fundamentals. As distinct from the flow model discussed in Section 7.2.2 the present random-walk model of the exchange rate does not distinguish between these two possibilities. INV_t denotes the volume of sterilized central bank intervention. Positive (negative) values represent purchases (sales) of foreign currency by the domestic central bank. The coefficient δ^V

measures the effect of sterilized interventions. Purchases (sales) of foreign currency should lead to an increase (decrease) in the value of foreign exchange. Therefore, effective interventions are associated with a positive value of δ^V.

7.3.3 Derivation of the intervention reaction function and the loss of the central bank

The random-walk model of the exchange rate can again be combined with a central bank policy loss function. Regarding the exact specification of the loss function it is important to note that the stochastic term in (7.12) introduces uncertainty into the model. One approach would be to assume that the central bank can easily cope with this kind of uncertainty. For instance, it can be asserted that central bank intervention is a highly flexible policy instrument which can be implemented at any point in time. Therefore, the central bank can be thought of as monitoring the exchange rate carefully with interventions being conducted after the realization of the shock ϵ_t. When, in addition, one believes in the manageability of the exchange rate in the short run it may make sense to think of the central bank as pursuing a target level of the exchange rate. Under these circumstances the loss function in equation (7.9) above, repeated here as equation (7.13), still applies:

$$L_t^{CB} = (s_t - s_t^T)^2 \tag{7.13}$$

As before, the intervention reaction function can be obtained by minimizing the loss function (7.13) with respect to the volume of intervention INV_t and after substitution of equation (7.12):

$$INV_t = -\frac{1}{\delta^V}(a + s_{t-1} - s_t^T + \epsilon_t) \tag{7.14}$$

A staightforward implication of the random-walk model in (7.12) is that the best prediction of the exchange rate at time t conditional on no intervention is $a + s_{t-1}$. This is also reflected in the reaction function (7.14) which states that the central bank buys amounts of domestic currency ($INV_t < 0$) when its best guess of the current exchange rate ($a + s_{t-1}$) is higher than the current exogenous target rate (s_t^T). Equation (7.14) implies that the central bank will buy additional domestic currency in the event of a positive shock to the exchange rate, i.e. a positive realization of the disturbance term ϵ_t.[6] The volume of intervention is higher, *ceteris paribus*, the lower the value of the effectivity coefficient δ^V. Clearly, the more effective the interventions are, the smaller the volume of intervention that is required to stabilize the exchange rate around s_t^T in spite of permanent (a) and transitory (ϵ_t) shocks impinging on it.

After substituting the intervention reaction function (7.14) into the exchange rate equation (7.12) and the resulting equation into the loss function (7.13), it turns out that the value of the central bank loss function in the present stochastic game against nature is equal to zero, i.e. $L_t^{CB} = (s_t - s_t^T)^2 = 0$. Below it will become clear that this result depends crucially on the assumption that the central bank carries out interventions only after the transitory shock ϵ_t is realized. Given the assumed unlimited availability of foreign exchange reserves the central bank can attain the objective embodied in a different loss function as well. It may for example want to limit exchange rate changes *per se*. This can be captured by a loss function which is quadratic in the percentage change of the exchange rate:

$$L_t^{CB} = (s_t - s_{t-1})^2 \tag{7.15}$$

This implies that the central bank is equally averse to appreciations and depreciations of the domestic currency. The reaction function obtained by substituting (7.12) into (7.15) and differentiating the resulting relation with respect to the volume of intervention, can be written:

$$INV_t = -\frac{1}{\delta^V}(a + \epsilon_t) \tag{7.16}$$

By making use of equations (7.12), (7.16) and (7.15) it can easily be derived that the value of the central bank loss function is again equal to zero, i.e. $L_t^{CB} = (s_t - s_{t-1})^2 = 0$.

7.3.4 Bandwagon effects in exchange rate dynamics and intervention

If the central bank carries out interventions only after the transitory shock ϵ_t is realized and when there is no physical limit to the foreign exchange reserves, the central bank can attain the objective embodied in the loss function irrespective of the exact stochastic exchange rate process. For instance, assume that there are bandwagon effects in exchange rate dynamics (Takagi 1991, Lai and Pauly 1992). Suppose, specifically, the exchange rate follows a process as

$$s_t - s_{t-1} = \phi\,(s_{t-1} - s_{t-2}) + \delta^V INV_t + \epsilon_t, \qquad \epsilon_t | \Omega_{t-1} \sim N(0,\sigma_\epsilon^2) \tag{7.17}$$

where $\phi > 0$. This occurs when a rise (fall) in the exchange rate generates anticipations of a further rise (fall). The central bank may want to resist the effect of bandwagon expectations among speculators. With the loss function given by (7.15) the resulting intervention reaction function can be written:

$$INV_t = -\frac{1}{\delta^V}\left(\phi(s_{t-1} - s_{t-2}) + \epsilon_t\right) \tag{7.18}$$

When the central bank intervenes according to (7.18) its loss can again be shown to be equal to zero.

7.3.5 Countering transitory shocks in real time

The foreign exchange market is a global market on which trading takes place 24 hours a day. Moreover, the market is hit by 'news' almost continuously. As a consequence of this, in practice, the exact realization of the shock ϵ_t is known only at the very end of day t. It does not seem to be realistic to assume that the central bank waits for this to compute and carry out the optimal volume of intervention. However, in line with that, it can also be argued that the central bank will not react to unexpected events which occur during the first half of the trading day: unexpected events announced during the second half of the trading day may have an opposite effect on the exchange rate making $\epsilon_t = 0$. In view of this it seems reasonable to assume that the central bank only wants to minimize the *expected* divergence between the actual exchange rate and the target value. In that case the loss function can be written:

$$L_t^{CB} = E_{t-1}(s_t - s_t^T)^2 \tag{7.19}$$

The intervention reaction function obtained by minimizing the loss function (7.19) with respect to the volume of intervention INV_t and after substitution of equation (7.12) is given by

$$INV_t = -\frac{1}{\delta^V}\left(a + s_{t-1} - s_t^T\right) \tag{7.20}$$

What stands out from the comparison of the reaction functions in (7.14) and (7.20) is that in the latter case the central bank does not react to the realization of the transitory shock ϵ_t. As a consequence of the fact that the central bank tries to compress the *expected* rather than the actual gap between the actual exchange rate and the target value conditional on no intervention, the expected loss is positive and proportional to the variance of the transitory shock ϵ_t:

$$E_{t-1}L_t^{CB} = E_{t-1}(\epsilon_t)^2 = \sigma_\epsilon^2 \tag{7.21}$$

In practice, the central bank can not counteract all transitory shocks in real time. However, from an analytical point of view this poses no problem.[7] Therefore, in the remainder of this chapter it will be assumed that the central bank intervenes in the foreign exchange market at the end of period t and that it reacts to shocks which materialized between the end of period t—1 and the end of period t.

7.3.6 Introducing costs of intervention

To arrive at an expected loss of zero it is not only crucial to assume that the central bank carries out interventions after the transitory shock is realized. In addition to that, the effectivity coefficient δ^V has to be sufficiently high or foreign exchange reserves have to be unlimited. Neither of the latter two conditions holds in practice. In fact, interventions seem to have a fairly negligible effect on the balance of supply and demand in the foreign exchange market. Consequently, the chance that interventions are able to drive the exchange rate into the direction favoured by the central bank and against the current market sentiment is small. To take account of that I assume that there are costs involved in conducting official operations in foreign exchange. There may be bureaucratic costs involved in deciding on the volume of intervention. Furthermore, the costs of intervention may take the form of losses on the net foreign currency position of the central bank caused by purchases (sales) of foreign currency which turn out to be unsuccessful at preventing the domestic currency from appreciating (depreciating). To proxy the costs of intervention the value of the central bank loss function increases more than proportionally with the volume of intervention:

$$L_t^{CB} = \frac{1}{2}(c\ INV_t)^2 + \frac{\alpha}{2}(\Delta\ s_t - a)^2 \tag{7.22}$$

where c is a factor of proportionality for the costs of intervention and the coefficient α measures the weight assigned to limiting exchange rate changes. The first term on the right-hand side of (7.22) reflects that the higher the volume of intervention the higher the potential financial losses on the net foreign currency position of the central bank caused by purchases (sales) of foreign currency which turn out to be unsuccessful at preventing the domestic currency from appreciating (depreciating). Of course, potential financial gains from interventions which turn out to be effective also increase with the volume of intervention. However, if central banks are risk averse and if they are aware of the relative negligibility of interventions on the balance of supply and demand in the foreign exchange market, they will limit the chance of losing money by intervening too heavily.[8]

In principle, exchange rate stability is a public good. The second term on the right-hand side of (7.22) reflects that central bank losses increase more than proportionally with changes in the exchange rate which are not caused by the relative state of the 'fundamentals' of the domestic economy. For instance, in the next section it is argued that the exchange rate may experience a predictable a per cent rise due to the domestic inflation rate being persistently higher than the foreign one. This depreciation may be at odds with the monetary authorities' attempts to stabilize the exchange rate and to maintain the external equilibrium of the domestic economy. By assumption, however, priority is given to domestic monetary policy. Therefore, interventions are not directed at countering the a per cent change which is a direct result of the outcome of monetary policy.

The intervention reaction function is obtained by substituting the stochastic process for the exchange rate in equation (7.12) into the loss function (7.22) and differentiating the resulting relation with respect to the volume of intervention. It can be written:

$$INV_t = -\frac{\alpha\,\delta^V}{c^2 + \alpha\,(\delta^V)^2}\,\epsilon_t \tag{7.23}$$

The introduction of costs of intervention alters the behaviour of the central bank. It can easily be seen by comparing the intervention reaction functions in (7.16) and (7.23) that positive costs of intervention lower the intervention coefficient in absolute value.[9] When interventions are costless, the central bank fully counteracts all shocks to the exchange rate. Moreover, it was noted before that a higher effectivity coefficient (higher value of the positive coefficient δ^V) simply means that smaller amounts of intervention are required to stabilize the exchange rate. Compare this with the case of positive costs of intervention. An increase in the effectiveness of intervention allows the central bank to make a more favourable trade-off between the costs and the benefits of intervention. It turns out that a higher effectivity leads *ceteris paribus* to a higher volume of intervention as long as $\delta^V < c\,/\,\sqrt{\alpha}$, i.e. as long as the initial effectivity is below a certain threshold level.[10] This threshold level is increasing in the costs of intervention and decreasing in the central bank's weight to exchange rate stability. It can easily be seen from equation (7.23) that a high value of c and a low value of α both contribute to a low equilibrium volume of intervention.[11] When the initial equilibrium volume of intervention is low the costs of intervention do not weigh too heavily and the central bank increases the volume of intervention in response to a rise in δ^V.

The value of the central bank loss function can be computed by substituting (7.12) and (7.23) into (7.22). It is given by

$$L_t^{CB} = \frac{1}{2}\,\frac{c^2\,\alpha}{c^2 + \alpha\,(\delta^V)^2}\,\epsilon_t^2 \tag{7.24}$$

Clearly, the loss is increasing in α and c but decreasing in δ^V. Thus, although an increase in the effectivity of intervention does not necessarily lead to an increase in the volume of intervention (see note 10) it unambiguously leads to a lower loss of the central bank. This is due to the fact that a rise in δ^V allows the central bank to make a less unfavourable trade-off between the costs and benefits of intervention.

7.3.7 Intervention as a stochastic game against nature: evaluation

In this section a random-walk model for the exchange rate was used to analyse a stochastic exchange rate policy game against nature. The central bank intervenes in the foreign exchange market at the end of period t, after the transitory shock to the exchange rate is realized. It was found that the exchange rate can be stabilized if the interventions are sufficiently effective or foreign exchange reserves are unlimited. Neither of these conditions holds in practice. In fact, the exact channel through which central bank intervention affects the exchange rate was not made explicit in the random-walk model. Presumably, sterilized interventions exert an effect on the exchange rate through the portfolio balance channel. However, it appeared from Chapter 3 that there is only a small chance that sterilized interventions are able to influence the course of the exchange rate. To take account of that it was assumed that there are costs involved in conducting interventions. Depending on the exact shape of its loss function the central bank makes a trade-off between the costs and the benefits of intervention. Positive costs of intervention lower the intervention coefficient but increase the loss of the central bank. Bhattacharya and Weller (1992) argue that one should not build on the portfolio balance channel of intervention. According to them, the introduction of strategic behaviour by central banks can alter the scope for intervention dramatically. In the next section I will explore the strategic interaction between the central bank on the one hand and private speculators on the other hand.

7.4 INTERVENTION AS A GAME AGAINST RATIONAL MARKET PARTICIPANTS[12]

7.4.1 Introduction

It is a fact of observation that private exchange market participants are eager to detect any information related to official operations in foreign currency. Therefore, it seems sensible to abandon the implicit assumption of Sections 7.2 and 7.3 that the central bank is regarded by private exchange market participants as 'just another exchange market participant'. On the other hand, central bankers know that their actions are monitored very carefully. Consequently, to make reasonable inferences on the impact of foreign exchange interventions it seems that strategic considerations surrounding the actions of central bankers in the market for foreign exchange have to be taken into account. Section 2.4 briefly explored the implications of non-fundamentalist trading strategies by currency traders for the actions to be taken by central banks to render interventions effective. The remainder of this chapter retains the assumption of rational expectations among foreign exchange market participants. First, I will present a basic model with symmetric information and analyse the exchange rate policy game it embodies. Then I will discuss the approach taken by Bhattacharya and Weller (1992). They stress that central banks may have more information about their own targets than private speculators (asymmetric information). In that case 'the exchange rate communicates information' to the private sector, ensuring that 'large scale intervention is not required to affect exchange rates' (Bhattacharya and Weller 1992, p. 4).

7.4.2 Monetary policy and exchange rate policy

An extensive body of literature now exists which analyses monetary policy games (for surveys, see e.g. Blackburn and Christensen 1989, Argy 1992, Cukierman 1992, Ch. 2—7 and Sijben 1992). A game-theoretic analysis of the incentives facing monetary authorities when they manage the external rather than the internal value of the domestic currency has only recently attracted attention. Horn and Persson (1988), Holden (1991), Rasmussen (1993) and Alogoskoufis (1994) go beyond refining the familiar inflation—unemployment trade-off. Holden (1991, p. 1543) recognizes that 'a government may feel tempted to exploit the short run rigidity of wages, and devalue in order to obtain a short run gain in terms of improved competitiveness'.[13] However, for countries which committed themselves to the Articles of Agreement of the

International Monetary Fund (IMF) competitive devaluations do not seem to be a feasible policy option.[14]

In general, the monetary authorities of large industrialized countries give priority to domestic policy objectives. The instruments of monetary policy are basically used to attain these objectives. Appendix A7.1 sets out a static monetary policy game between wage-setters and the central bank. When setting the money supply the monetary authorities make a trade-off between the benefits and the costs of an actual higher-than-expected increase in the domestic money supply. In the symmetric information case considered in Appendix A7.1 the private sector anticipates the central bank's temptation to engage in surprise inflation. It follows that the economy is caught up in a Nash equilibrium which is characterized by an inefficiently high level of inflation but with output unchanged at its natural level.[15] Appendix A7.1 derives the optimal time-consistent domestic inflation rate $\hat{\pi}_t$ set by the domestic monetary authorities. Analogously, the inflation rate set in a foreign country $\hat{\pi}_t^*$ will be the outcome of a similar monetary policy game. However, similar monetary policy games at home and abroad may lead to different optimal time-consistent inflation rates for the domestic and foreign economy.

Suppose private exchange market participants recognize that the underlying trend in the exchange rate is determined by PPP considerations. On the assumption that they have at least the same information as trade unions at home and abroad, they can compute the expected inflation rate for the domestic and the foreign economy and, hence, the expected PPP-implied change in the exchange rate

$$E_{t-1}\, \Delta\, s_t^{PPP} = E_{t-1}\, \hat{\pi}_t - E_{t-1}\, \hat{\pi}_t^* \equiv a \qquad (7.25)$$

The inflation differential is measured on a yearly basis. Under normal circumstances the PPP component of daily exchange rate changes will be negligible. Moreover, for short-term exchange rate determination the whims of speculators and institutional investors can be much more important than inflation differentials between countries. Still, equation (7.25) underlies the exchange rate equation in the exchange rate policy game against rational speculators.

7.4.3 The determination of the exchange rate

Consider the following stochastic exchange rate equation:

$$\Delta\, s_t = a + \delta^V\, INV_t + \delta^E\, (INV_t - INV_t^e) + \epsilon_t, \qquad \epsilon_t \sim N(0,\, \sigma_\epsilon^2) \qquad (7.26)$$

where s_t is the log of the foreign exchange rate (units of domestic currency per unit of foreign currency). INV_t and INV_t^e denote the actual volume of intervention (purchases of foreign currency by the domestic central bank) and private exchange market participants' expected volume of intervention, respectively. It is important to note that speculators determine INV_t^e upon observation of ϵ_t, the stochastic shock to the exchange rate.[16] When the actual and expected volume of intervention are both zero (i.e., when $INV_t = INV_t^e = 0$) and when the stochastic shock to the exchange rate ϵ_t takes on a value of zero, the domestic currency experiences a constant a per cent depreciation ($a > 0$) or appreciation ($a < 0$) *vis-à-vis* the foreign currency per time period. In fact, in the latter case the exchange rate equation reduces to the PPP relation in (7.25). Obviously, if a is positive (negative) the domestic inflationary bias is higher (lower) than the foreign one.

Compared to individual private currency dealers, the central bank may be viewed as a relatively big player in the market. However, intervention volumes are very tiny compared to the total daily turnover on the foreign exchange market.[17] Consequently, the course of the exchange rate is not likely to be affected by the very volume of intervention. In spite of that, equation (7.26) does allow sterilized interventions to affect the exchange rate through the portfolio balance channel.[18] This effect is measured by the coefficient δ^V. If δ^V is positive the volume of intervention itself matters with purchases (sales) of foreign currency affecting the exchange rate positively (negatively). The negligibility of intervention volumes compared to the average daily turnover on the foreign exchange market implies that $\delta^V = 0$. Equation (7.26) also leaves open the possibility that central bank intervention works through the expectations channel. Actual higher-than-expected interventions may catch private speculators off balance and, hence, lead to a correction in the exchange rate. The expectations channel is operative if $\delta^E > 0$. This implies that actual larger-than-expected purchases (sales) of foreign currency affect the exchange rate positively (negatively).[19]

7.4.4 Central bank behaviour

The loss function of the central bank is identical to equation (7.22) in the previous section. It is repeated here for convenience as equation (7.27)

$$L_t^{CB} = \frac{1}{2}(c\ INV_t)^2 + \frac{\alpha}{2}(\Delta s_t - a)^2 \tag{7.27}$$

The central bank is assumed to make a trade-off between the costs of interventions in the spot market for foreign exchange and the losses from fluctuations in the exchange rate. The first term on the right-hand side of (7.27) proxies the costs of intervention. The value of the central bank loss function increases more than proportionally with the volume of intervention. The second term on the right-hand side of (7.27) reflects the fact that central bank losses increase more than proportionally with changes in the exchange rate which are not caused by the differential inflationary biases at home and abroad. Above it was argued that the different outcomes of the monetary policy games between the central bank and workers in the domestic and the foreign economy initially resulted in an a per cent per period depreciation of the domestic currency (of course, when a is negative the domestic currency appreciates). This depreciation may be at odds with, for instance, the monetary authorities' attempts to stabilize the exchange rate and to maintain the external equilibrium of the domestic economy. However, it is assumed that the central bank gives priority to domestic monetary policy and that it will not direct exchange rate policy at counteracting exchange rate movements which are a direct result of the outcome of the monetary policy game.

7.4.5 The behaviour of rational speculators

The foreign exchange market is hit by 'news' almost continuously. This frequent arrival of new information causes currency traders' positions to be in a permanent state of flux. Each exchange market participant bases position-taking on his prediction of the market's interpretation of, and reaction to news and rumours (Almekinders and Rovers 1994). This translates into a stochastic shock to the exchange rate ϵ_t. Obviously, this stochastic shock is the outcome of a kind of information game among well-informed private exchange market participants (Lyons 1991).

By assumption, strategic interaction between the central bank on the one hand and private exchange market participants on the other hand comes into play only after the shock ϵ_t has materialized.[20] Therefore, for the exchange rate policy game analysed here, issues of intra-private sector behaviour are of no concern.[21] The diverse group of foreign currency traders will be treated as one representative agent. The loss function of the representative speculator can be written:

$$L_t^{PS} = \frac{1}{2}\,(INV_t^e - INV_t)^2 \tag{7.28}$$

where INV_t^e denotes the speculator's expectation regarding the volume of intervention to be carried out by the central bank in period t. To make sure, the realization of the shock ϵ_t is contained in the information set of the speculator when he computes this expectation. The loss function in

(7.28) reflects speculators' aversion to being fooled by the central bank.

7.4.6 The Nash equilibrium of the exchange rate policy game

The strategic interaction between the central bank and the representative speculators takes place after the shock to the exchange rate has occurred. Hence, although there is a stochastic element in the exchange rate model, the exchange rate policy game is essentially deterministic. The timing of events is illustrated in Table 7.1.

Table 7.1 Timing of events in the exchange rate policy game

Stage 1	Stage 2	Stage 3
Interaction among the various sorts of private exchange market participants leads to a shock to the exchange rate ϵ_t	Shock to the exchange rate ϵ_t is observed by both the central bank and the private sector	The central bank and the private sector simultaneously set INV_t and INV_t^e, respectively

Upon observing the speculative shock to the exchange rate, the monetary authorities attempt to minimize period t's policy loss, taking the expectations of private exchange market participants, INV_t^e, as given (the Nash assumption). The central bank's reaction function to the expectation of the representative private exchange market participants is obtained from the first-order condition for a minimum of (7.27), i.e. $\partial L_t^{CB} / \partial INV_t = 0$, after substituting equation (7.26) into it:

$$INV_t = \frac{\alpha(\delta^V + \delta^E)}{c^2 + \alpha(\delta^V + \delta^E)^2} \left[\delta^E \, INV_t^e - \epsilon_t\right] \tag{7.29}$$

According to equation (7.29) the domestic central bank partly accommodates private exchange market participants' expectations regarding the volume of intervention.[22] Clearly, private exchange market participants minimize period t's losses by setting

$$INV_t^e = INV_t \tag{7.30}$$

An expression for equilibrium intervention is obtained by substituting this reaction function in (7.29):

$$INV_t = -B\,\epsilon_t, \quad \text{where} \quad B = \frac{\alpha(\delta^V + \delta^E)}{c^2 + \alpha\delta^V(\delta^V + \delta^E)} \tag{7.31}$$

Figure 7.1 shows the central bank's reaction function for the case of a negative shock to the domestic currency value of foreign currency, i.e. $\epsilon_t < 0$.[23] Thus, it depicts the volume of intervention as a function of the expected volume of intervention in a situation in which purchases of foreign currency are called for. The only point at which expectations are rational is at point *N*, the intersection of the central bank's reaction function and the 45°-line through the origin. This represents the Nash equilibrium. This equilibrium, which is also called the 'discretionary equilibrium' or the 'time consistent solution' in the 'rules versus discretion' literature, is unique in this one-shot game. If private exchange market participants expected a lower volume of intervention, in absolute terms, than what is implied by (7.31), the central bank would have an incentive to carry out surprise interventions. Thus, expectations would not turn out to be rational.[24] Intervention expectations rise to the point where there are no further incentives for the central bank to create

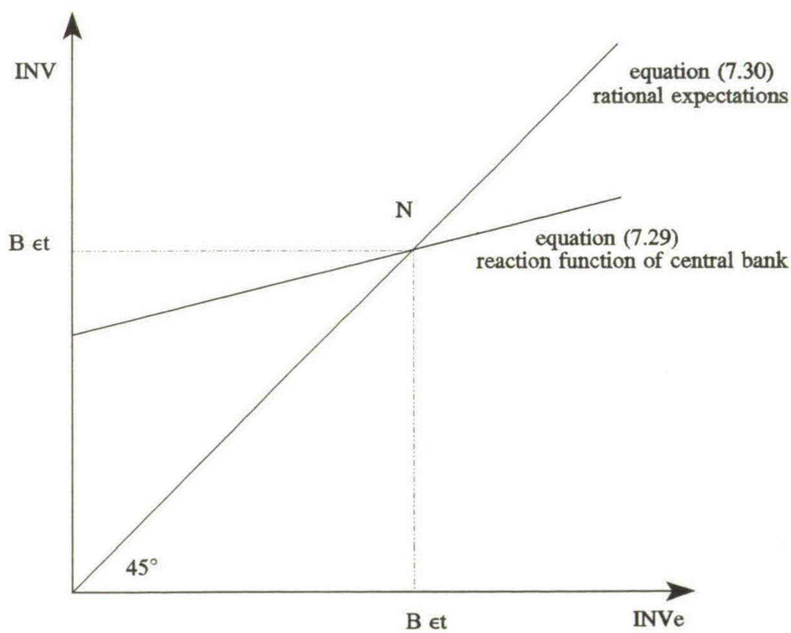

Figure 7.1 Actual and expected intervention in the presence of a positive shock to the demand for domestic currency which the domestic central bank wants to counteract

surprise interventions. Analogous to the well-known 'inflationary bias' of discretionary monetary policy analysed by Barro and Gordon (1983a,b) and Alogoskoufis (1994) this is the 'intervention bias' of discretionary exchange rate policy. The volume of intervention at point N is given by equation (7.31). However, what stands out from equation (7.30) and Figure 7.1 is that in equilibrium intervention is fully anticipated. Substituting (7.30) in the exchange rate equation (7.26) gives

$$\Delta s_t = a + \delta^V INV_t + \epsilon_t \tag{7.32}$$

Equations (7.31) and (7.32) highlight the time inconsistency of optimal intervention policy. The intervention policy of the central bank described by equation (7.29) is time-consistent in the sense that at each point in time the volume of intervention selected is best, given the current situation. However, as can be seen from equations (7.31) and (7.32), the resulting non-cooperative equilibrium of the exchange rate policy game has an inefficient 'intervention bias'. It is inefficient to carry out the non-zero equilibrium amount of intervention associated with the Nash equilibrium in point N because the costs involved are not offset by any benefits. The nonzero amount of intervention is fully anticipated by the private sector. Therefore, it is not successful at limiting the impact of the initial shock to the exchange rate through the expectations channel. Gains in the form of systematically smaller exchange rate changes are only to be expected if the portfolio balance channel is operative ($\delta^V > 0$).

The value of the central bank loss function can be computed by substituting (7.26) and (7.31) into (7.27). It is given by

$$L_t^{CB} = \frac{1}{2} \frac{c^2 \alpha (c^2 + \alpha (\delta^V + \delta^E)^2)}{(c^2 + \alpha \delta^V (\delta^V + \delta^E))^2} \epsilon_t^2 \tag{7.33}$$

7.4.7 Intervention as a game against rational speculators: evaluation

In Section 7.3.7 doubts were raised about the significance of the effect of interventions working through the portfolio balance channel; the presumed low value of δ^V was the main reason to investigate the expectations channel of intervention and to explore the concomitant strategic interaction among official and private exchange market participants. The implications of the strategic interaction can be inferred by comparing the expressions for the optimal volume of intervention and the loss of the central bank in the game against nature and the game against rational speculators, respectively.

The intervention reaction coefficient in (7.23) is smaller in absolute value than the one in (7.31).[25] Strategic interaction creates some new room for discretionary exchange rate policy. It allows the central bank to affect the exchange rate through the expectations channel of intervention. However, it is assumed that the central bank and private speculators have an equal status and full information regarding each other's objective functions. In the end, the central bank finds itself forced to fully use up its room for discretion and engage in more voluminous intervention than what is optimal from its individual point of view. Yet, the exchange rate equation (7.32) which applies in the Nash equilibrium of the game against rational speculators is the same as the exchange rate equation (7.12) which was used to analyse the game against nature. Therefore, it can easily be seen that society as a whole, which is presumably interested only in smaller exchange rate changes, on average only benefits from the higher volume of intervention to the extent that the volume effect of intervention (δ^V) is larger than zero. In any case, the central bank can be shown to be unambiguously worse off.[26]

7.4.8 The sensitivity of intervention policy to changes in the preferences of the central bank

This section investigates the effect of changes in α, the weight assigned by the central bank to limiting fluctuations in the exchange rate around the PPP-implied fundamental trendline. It was noted before that there are many similarities between the present exchange rate policy game and standard monetary policy games. A basic assumption in monetary policy games is that due to existing distortions the market-clearing level of output is lower than the monetary authorities' target level. The parameter which denotes the relative weight the central bank places on output compared to inflation is of crucial importance in the monetary policy game. A well-known result in the literature on monetary policy games is that the higher the central bank's weight on output, the greater the incentive to create surprise inflation. In many studies the parameter for the central bank's weight on output is interpreted as the inverse of the degree of central bank independence (Rogoff 1985, Eijffinger and Schaling 1993b, Debelle 1993). The idea behind this is that a central bank knows that in the long run it can not systematically stimulate output by means of surprise inflation. Consequently, a central bank will only engage in larger-than-expected monetary expansions if it is forced to do so by politicians and if it is not protected from their influence by law.

In the previous section it was established that the central bank is not able to limit systematically the impact of realized shocks to the exchange rate by means of interventions which work through the expectations channel. Consequently, a central bank which is independent from political incumbents will in general not stubbornly resist these shocks to the exchange rate. As shown, for instance, by Cukierman (1992) and Eijffinger and Schaling (1993a), in most countries central banks are highly dependent on the government in general and the minister of finance in particular. As a result, the policies implemented by central banks are not independent from the general political process. For instance, a persistent appreciation of the domestic currency will lead domestic exporters to complain to the minister of finance about their declining competitiveness on the world market. A central bank which lacks autonomy in the field of exchange rate policy may be forced by the ministry of finance to engage in highly visible foreign exchange intervention; political incumbents will want to show that they are really concerned with the competitiveness of domestic exporters. The converse of this argument is as follows. The greater the independence given to the central bank by law, the smaller the political influence on exchange rate policy and the smaller the pressure on the central bank to systematically counteract speculative shocks to the exchange rate. Analogous to the monetary policy game, the notion of central bank independence can be incorporated in the present exchange rate policy game by taking the weight α in the central bank loss function in (7.27) to measure the inverse of the independence of the central bank.

Regarding the intervention reaction coefficient in (7.31) it can be shown that $\partial B / \partial \alpha > 0$ and $\partial^2 B / \partial \alpha^2 < 0$. Consequently, the higher the weight given by the central bank to reducing changes in the exchange rate which are larger in absolute value than those implied by PPP, i.e. the higher the value of α, the larger the intervention bias. From this Proposition 7.1 can be derived.

Proposition 7.1: The more independent the central bank, the smaller the average volume of intervention.

From

$$\lim_{\alpha \to \infty} B = \lim_{\alpha \to \infty} \frac{\alpha(\delta^E + \delta^V)}{c^2 + \alpha\delta^V(\delta^V + \delta^E)} = \frac{1}{\delta^V} \tag{7.34}$$

it follows that when the central bank is averse to non-fundamental exchange rate changes the intervention reaction coefficient in (7.31) converges to the inverse of the coefficient which measures the 'volume effect' of intervention. This happens to be the same intervention reaction coefficient as in the game against nature analysed in Section 7.3.3 in which $\delta^E = 0$. Figure 7.2 shows how the intervention reaction coefficient in (7.31) changes with an increasing aversion of the central bank to speculative shocks to the exchange rate. When α goes to infinity the central bank (or the politicians which determine its policy) is not bothered by the costs of intervention. In a full information exchange rate policy game private speculators know the value of α. Consequently, when α is very high they know that the central bank is going to counteract realized shocks to the exchange rate (ϵ_t) as fiercely as possible. As a result, the expectations channel of influence of interventions does not work at all. The mere 'volume effect' of intervention has to do the job. This implies that the central bank will have to try to affect the exchange rate through the portfolio balance channel of intervention. Clearly, when δ^V is very small the average volume of intervention goes to infinity.

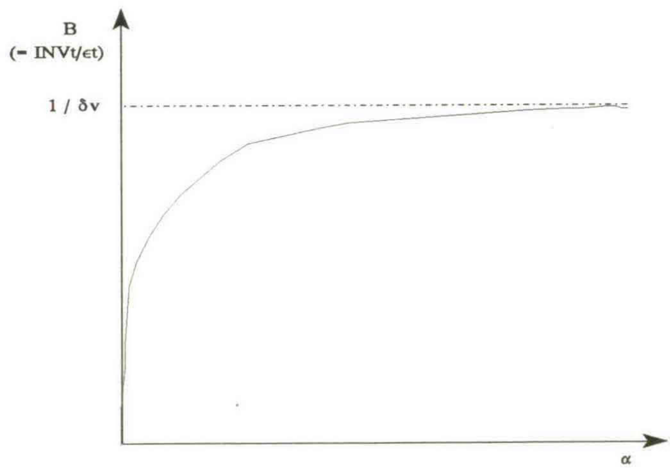

Figure 7.2 The central bank's aversion to shocks to the exchange rate and the intervention reaction coefficient

The variability of the volume of intervention is also sensitive to changes in the central bank's aversion to non-fundamental changes in the exchange rate. Taking variances of (7.31) gives $Var\ (INV_t)/\sigma_\epsilon^2 = B^2$. From

$$\lim_{\alpha \to \infty} \frac{Var\ (INV_t)}{\sigma_\epsilon^2} = \lim_{\alpha \to \infty} B^2 = \lim_{\alpha \to \infty} \left[\frac{\alpha(\delta^E + \delta^V)}{c^2 + \alpha\delta^V(\delta^V + \delta^E)} \right]^2 = \frac{1}{(\delta^V)^2} \quad (7.35)$$

it follows that, if the central bank gives an infinite weight to stabilizing the exchange rate around PPP levels, the variance of the volume of intervention is positively related to the variance of shocks to the exchange rate, σ_ϵ^2, and inversely related to the effectiveness of interventions via the portfolio balance channel. Obviously, $\partial B^2 / \partial \alpha > 0$. This implies that a higher weight to limiting changes in the exchange rate leads to a higher variance of the volume of intervention relative to the variance of the shock to the exchange rate. From this Proposition 7.2 can be derived.

Proposition 7.2: The more independent the central bank, the lower the variance of the volume of intervention.

Figure 7.3 shows how the relative variability of the intervention volume changes with an increasing aversion of the central bank to speculative shocks. Equating to zero the second derivative of B^2 with respect to α obtains a point of inflection at $\alpha = c^2/(2\ \delta^V(\delta^V + \delta^E))$. From equation (7.31) it follows that the higher the costs of intervention, c, the smaller *ceteris paribus* the equilibrium volume of intervention. When the weight α increases, the central bank is relatively less concerned with the costs of intervention. This leads to a catch-up effect with the variability of intervention (compared to σ_ϵ^2) initially rising fast. When α is above the value corresponding to the point of inflection the shape of the central bank loss function in (7.27) implies that the costs of intervention start to weigh more heavily again. Consequently, a rise in α leads to a slower rise in the relative variability of the volume of intervention.

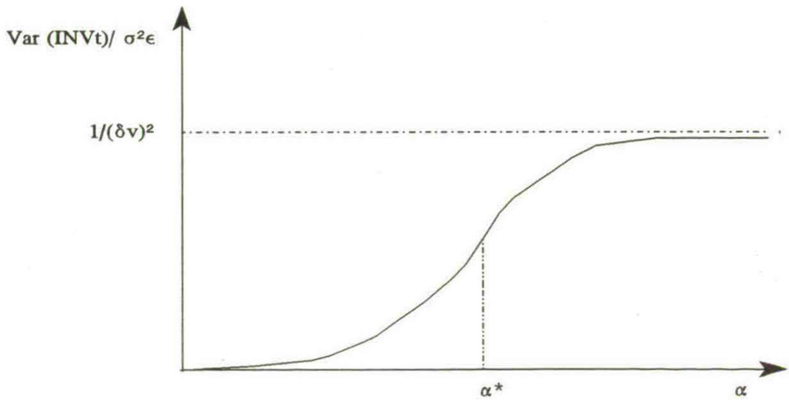

Figure 7.3 The central bank's aversion to shocks to the exchange rate and the variability of the volume of intervention

7.4.9 The link between intervention efforts and central bank independence: some cross-country evidence

Sections 7.4.2 to 7.4.7 presented a simple game-theoretic model of exchange rate policy. Section 7.4.8 established that the model implies a negative correlation between the degree of central bank independence and the magnitude and variability of the volume of intervention. In this section it will be investigated whether these negative correlations are supported by cross-country evidence. The Eijffinger—Schaling (ES) index of policy independence developed in Eijffinger and Schaling (1993a) will be used as a measure of central bank independence.[27] This index is available for twelve major industrialized countries. For each of the twelve central banks the magnitude of the intervention efforts is proxied by the average absolute monthly percentage change in the foreign exchange reserves of the respective central bank. The variability of the volume of intervention is proxied by the variance of the absolute monthly percentage change in the central bank's foreign exchange reserves. The data on central bank independence and intervention efforts are depicted in Table 7.2.

The relationship between the degree of central bank independence and the magnitude and variability of the volume of intervention is analysed for the post-Bretton Woods period from February 1973 through to January 1993. Under the Bretton Woods system of fixed exchange rates all countries were fully committed to maintaining a fixed price of the US dollar in terms of their own currency. In the model in Section 7.4.2 it was assumed that central banks are free to choose the actual volume of intervention, i.e. they are not bound by international exchange rate arrangements. Therefore, the propositions derived from this model can not be tested with data covering a period during which central banks were obliged to conduct unsterilized interventions in the event of strains on the foreign exchange market.

Figure 7.4 shows a negative relation between the average absolute monthly percentage change in foreign exchange reserves and the ES index of central bank independence. Switzerland is a clear outlier in the figure. There are two obvious explanations for that. Firstly, Switzerland plays a central role in international banking and international investors often regard it as a safe haven. Consequently, foreign currency flows into the Swiss economy can at times be very large. The Swiss National Bank, like many other central banks, sometimes tries to limit the upward pressure on the external value of the Swiss franc by absorbing some of the foreign currency coming in from abroad. Secondly, it is an idiosyncrasy of Swiss commercial banks that they wish to exhibit higher

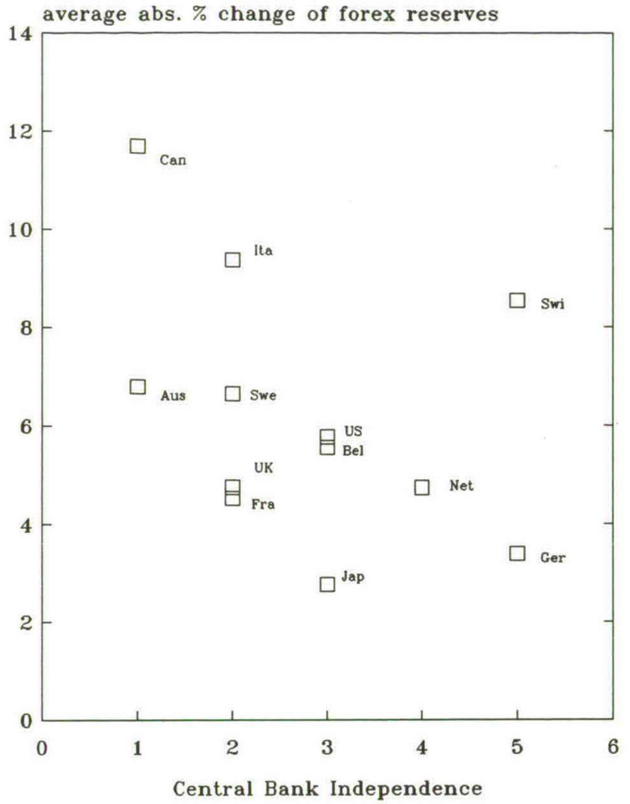

Figure 7.4 *Central bank independence and the average volume of intervention in twelve industrial countries*

end-of-quarter liquidity in terms of Swiss francs than they wish to maintain over the entire period. In order to smooth out the resulting daily money-market rate peaks, the Swiss National Bank offers end-of-quarter swaps to commercial banks (Gärtner 1987, p. 443). These swaps are completely unrelated to developments in the foreign exchanges. Yet, they are included in the monthly reserves data used in this section.

With Switzerland excluded from the sample, the negative correlation between the volume of intervention and the degree of central bank independence is supported by the results of a simple OLS regression depicted in the top row of Table 7.3.

The negative relation between the variability of the volume of intervention and the degree of central bank independence can be seen from Figure 7.5. The results of an OLS regression shown in the bottom row of Table 7.3 confirm this (again Switzerland is left out of the sample).

Table 7.2 Central bank independence and intervention efforts: February 1973—January 1993

Country	$ES\text{-}index_i$	$DRes_i$	$VarRes_i$
Australia	1	6.80	63.27
Canada	1	11.69	194.91
France	2	4.53	27.31
Italy	2	9.37	133.16
Sweden	2	6.65	49.25
United Kingdom	2	4.75	44.96
Belgium	3	5.56	38.99
Japan	3	2.77	13.13
United States	3	5.77	42.76
The Netherlands	4	4.74	26.42
Germany	5	3.39	20.13
Switzerland	5	8.54	62.67

Notes:
$ES\text{-}index_i$ denotes the index of central bank independence developed in Eijffinger and Schaling (1993a). The higher the index number, the more independent is the central bank from the political process.
The foreign exchange reserves data are taken from the International Financial Statistics of the IMF, *Foreign exchange reserves in millions of US dollars, line 1 D.D.* Upon denoting this monthly variable by R_t, $DRes_i$ the average monthly absolute percentage change in the foreign exchange reserves of country i is given by

$$DRes_i = \left[\frac{1}{240}\sum_{t=1973:2}^{1993:1}(|R_t - R_{t-1}|)/R_{t-1}\right]_i$$

$VarRes_i$, the variance of the monthly absolute percentage change in foreign exchange reserves of country i is given by

$$VarRes_i = \left[Var(|R_t - R_{t-1}|/R_{t-1})\right]_i = \frac{1}{240}\sum_{t=1973:2}^{1993:1}((|R_t - R_{t-1}|/R_{t-1}) - DRes_i)^2$$

Table 7.3 Central bank independence and the magnitude and variability of intervention: OLS estimation results Feb. 1973—Jan. 1993

Dependent variable	Constant	$ES\text{-}index_i$	$\bar{R}^2$
$DRes_i$	9.59 (6.37)	−1.41 (−2.62)	0.37
$VarRes_i$	129.82 (3.84)	−27.63 (−2.29)	0.30

Notes: The number of observation is eleven. *t*-statistics are in parentheses. $\bar{R}^2$ is the squared multiple correlation coefficient adjusted for degrees of freedom.

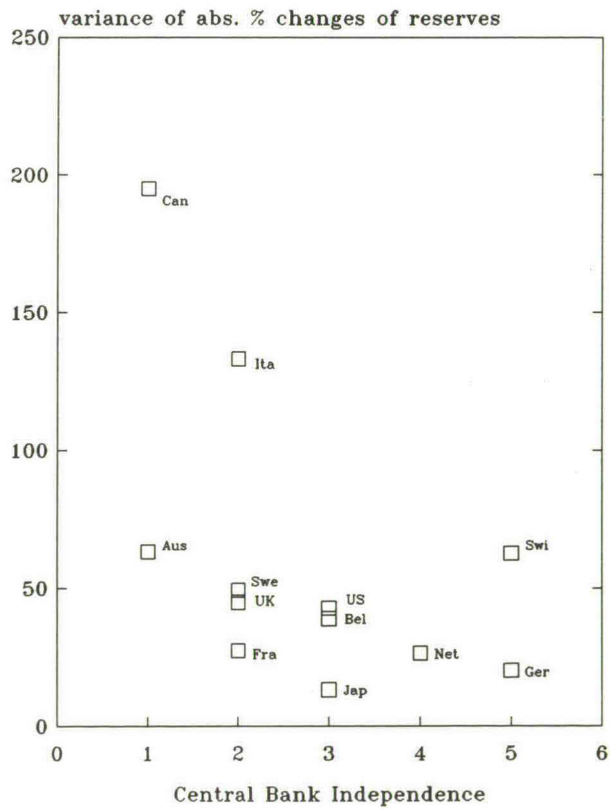

Figure 7.5 Central bank independence and the variability of intervention in twelve industrial countries

7.5 EXTENSIONS OF THE GAME AGAINST RATIONAL SPECULATORS

7.5.1 A dynamic extension

In Section 7.4.6 it was concluded that strategic interaction among official and private exchange market participants introduces an intervention bias. This result hinges on the presumed equal status of the central bank and the representative speculator and their having full information about each other's objective function. The central bank is forced to engage in more voluminous intervention than is optimal from its individual point of view. Moreover, interventions working through the expectations channel were found to be unable to lessen the impact of shocks to the exchange rate. A dynamic extension of the model does not lead to a more favourable picture regarding the central bank's ability to limit exchange rate fluctuations. In principle, in the full information environment characteristic of the non-cooperative Nash game there is nothing that links different time periods (Barro and Gordon 1983b). Consequently, the interaction between the players leads to an inefficient intervention bias in every period. The dynamic extension of the model involves generalizing the central bank policy loss function in equation (7.27):

$$L^{CB} = \sum_{t=1}^{\infty} \beta^t \left[\frac{c^2}{2} (INV_t)^2 + \frac{\alpha}{2} (\delta^V INV_t + \delta^E (INV_t - INV_t^e) + \epsilon_t)^2 \right] \quad (7.36)$$

where β is the discount factor applied to future losses of the central bank. Clearly, the term in brackets is period t's policy loss. As before, the central bank chooses INV_t to minimize the loss function in equation (7.36), taking INV_t^e as given. Since different time periods are not connected, minimization of equation (7.36) is equivalent to minimizing the loss function in (7.27) for each period separately. Hence, the Nash equilibrium discussed above results in each period. The equilibrium volume of intervention differs from period to period only to the extent that the shock ϵ_t takes on different values.

Game theorists have shown that in a repeated game non-cooperative players may settle upon more efficient outcomes than a repeated play of one-shot Nash outcomes. Intertemporal Friedman (1971) type trigger strategies on the part of the private sector can enforce 'good behaviour' of the monetary authorities. In the standard Barro—Gordon monetary policy game a low-inflation outcome can be enforced if the private sector adopts a trigger strategy, which takes the form of a reversion to the high discretionary wage inflation (the Nash equilibrium of the single-period game) if the central bank engages in surprise inflation.[28]

In the present exchange rate policy game an obvious trigger strategy for private exchange market participants is to (1) start by setting INV_t^e equal to zero; (2) continue setting $INV_t^e = 0$ in later periods unless the central bank has carried out a nonzero volume of intervention, and if the central bank has deviated from setting $INV_t = 0$, revert to the non-cooperative strategy for the rest of the game. However, the exchange rate policy game under consideration in this chapter contains a stochastic element. A new shock to the exchange rate ϵ_t is drawn each period. Canzoneri and Henderson (1991, pp. 95—9) show that in stochastic repeated games there are limits to the efficiency that can be achieved through the use of trigger strategies. For instance, in a period in which a large positive (negative) shock to the exchange rate ϵ_t is drawn, it will be beneficial for the central bank to set $INV_t < 0$ ($INV_t > 0$) and try to surprise private exchange market participants rather than to continue to set $INV_t = INV_t^e = 0$. Consequently, the trigger mechanism does not produce the right incentives.

7.5.2 Unequal status of the players

In Section 7.4.8 the notion of central bank independence was incorporated in the exchange rate policy game. The central bank's weight to exchange rate stability, α, was taken to measure the inverse of the political independence of the central bank. It was argued that the greater the independence given to the central bank by law, the smaller the pressure on the central bank to systematically counteract speculative shocks to the exchange rate. This interpretation of the value of α is not without flaws. It could, for instance, be read as implying that independent central banks do not care about exchange rate fluctuations. But what if a central bank is independent and yet has a high aversion to non-fundamental exchange rate changes? The policy loss function (7.27) with a high value of α may still apply.

Here a crucial difference between exchange rate policy and monetary policy comes to the fore. A primary responsibility of the central bank in the field of monetary policy is the *continuous* provision of base money to the domestic economy. The only discretion lies in the choice of the planned rate of growth of the money supply. By contrast, in the field of exchange rate policy the very involvement of the central bank in the determination of the exchange rate is at its own discretion. An independent central bank can choose to abstain from any intervention in the foreign exchange market. Put differently, the choice of the volume of intervention can imply an outright hands-off policy. This additional degree of freedom improves on the status of the central bank. In fact, it can be argued that the exchange rate policy game between an independent central bank and a representative speculator is a Stackelberg game.

In a Stackelberg game the players have no equal status. One of the players, the leader, acts before the other player, the follower. Therefore, there is an asymmetry in the availability of information to both players. The information set of the follower includes the action of the leader. Although the leader can not observe the follower's action, he can take advantage of the fact that the follower reacts on his action. On the assumption that the leader knows the exact shape of the follower's reaction function, the leader can choose the point on the follower's reaction function which minimizes his own loss function. Thus, the follower's reaction is endogenized in the leader's optimization problem.

Given the point made earlier, an independent central bank acts as a leader in the Stackelberg game. As a Stackelberg leader the central bank by definition acts *before* private speculators. Table 7.4 depicts the timing of events in the exchange rate policy game when the central bank is a Stackelberg leader. The relevant Stackelberg equilibrium is obtained, as before, by minimizing the central bank's loss function in (7.27) but only after substituting into it the speculator's reaction function.

Upon substitution of $INV_t^e = INV_t$, the loss function of the central bank reduces to

$$L_t^{CB} = \frac{c^2}{2}(INV_t)^2 + \frac{\alpha}{2}(\delta^V INV_t + \delta^E \cdot 0 + \epsilon_t)^2 \tag{7.37}$$

Differentiating with respect to INV_t and equating to zero yields an expression for the equilibrium volume of intervention for the case of Stackelberg leadership of the central bank:

$$INV_t = -\frac{\alpha\,\delta^V}{c^2 + \alpha(\delta^V)^2}\,\epsilon_t \tag{7.38}$$

A striking implication of this expression is the absence of an intervention bias. Apparently, a central bank which acts as a leader does not intervene at all when the portfolio balance channel of intervention does not work, i.e. when $\delta^V=0$.

Stackelberg leadership of the central bank is one extreme. One can also think of a central bank which completely lacks independence from the government. In that case the central bank may be forced by the minister of finance to smooth fluctuations in the exchange rate by means

Table 7.4 Timing of events in the exchange rate policy game when the central bank is Stackelberg leader

Stage 1	Stage 2	Stage 3
A shock to the exchange rate ϵ_t is drawn	ϵ_t is observed by both parties	The central bank sets INV_t. Thereby, INV_t^e is determined endogenously

of sterilized interventions. Under symmetric information the private sector is aware of the low status of the central bank and its obligation to repair any damage to the exchange rate. Private speculators will act as a Stackelberg leader in the exchange rate policy game. This changes the third stage of the game. Upon observing the shock to the exchange rate ϵ_t, private speculators set INV_t^e. Thereby, INV_t is determined endogenously.

An expression for the expected volume of intervention in the case of Stackelberg leadership of private speculators is obtained by minimizing their loss function in (7.28) with respect to INV_t^e after substituting into it the central bank's reaction function in (7.29). Upon substituting the resulting expression into the reaction function of the central bank it appears that

$$INV_t = INV_t^e = -\frac{\alpha(\delta^V + \delta^E)}{c^2 + \alpha\delta^V(\delta^V + \delta^E)}\,\epsilon_t \tag{7.39}$$

Thus, for the exchange rate policy game described by equations (7.26)—(7.28) there is no difference between Stackelberg leadership of the private sector and equal status of the players which leads to the Nash equilibrium as described in Section 7.4.6. This result depends crucially on the shape of the loss function of private speculators. Table 7.5 summarizes the impact of strategic interaction both for the loss of the central bank and the loss of the private sector.

7.5.3 Asymmetric information

In practice, for individual central banks one observes that periods of prolonged interventions in one direction are alternated by mostly much longer periods with no official operations in foreign exchange at all. This discontinuity in the interaction between the central bank and private

Table 7.5 The impact of strategic interaction on the outcome of the exchange rate policy game

	Actual volume of intervention	Expected volume of intervention	Loss of the central bank	Loss of the private sector
No strategic interaction	$INV_t = -\frac{\alpha\,\delta^V}{c^2 + \alpha\,(\delta^V)^2}\,\epsilon_t$		$L_t^{CB} = \frac{1}{2}\,\frac{c^2\,\alpha}{c^2 + \alpha\,(\delta^V)^2}\,\epsilon_t^2$	
Nash equilibrium	$INV_t = -\frac{\alpha(\delta^V + \delta^E)}{c^2 + \alpha\delta^V(\delta^V + \delta^E)}\,\epsilon_t$	$INV_t^e = -\frac{\alpha(\delta^V + \delta^E)}{c^2 + \alpha\delta^V(\delta^V + \delta^E)}\,\epsilon_t$	$L_t^{CB} = \frac{1}{2}\,\frac{c^2\,\alpha\,(c^2 + \alpha\,(\delta^V + \delta^E)^2)}{(c^2 + \alpha\,\delta^V\,(\delta^V + \delta^E))^2}\,\epsilon_t^2$	$L_t^{CB} = 0$
Stackelberg leadership of CB	$INV_t = -\frac{\alpha\,\delta^V}{c^2 + \alpha\,(\delta^V)^2}\,\epsilon_t$	$INV_t^e = -\frac{\alpha\,\delta^V}{c^2 + \alpha\,(\delta^V)^2}\,\epsilon_t$	$L_t^{CB} = \frac{1}{2}\,\frac{c^2\,\alpha}{c^2 + \alpha\,(\delta^V)^2}\,\epsilon_t^2$	$L_t^{CB} = 0$
Stackelberg leadership of PS	$INV_t = -\frac{\alpha(\delta^V + \delta^E)}{c^2 + \alpha\delta^V(\delta^V + \delta^E)}\,\epsilon_t$	$INV_t^e = -\frac{\alpha(\delta^V + \delta^E)}{c^2 + \alpha\delta^V(\delta^V + \delta^E)}\,\epsilon_t$	$L_t^{CB} = \frac{1}{2}\,\frac{c^2\,\alpha\,(c^2 + \alpha\,(\delta^V + \delta^E)^2)}{(c^2 + \alpha\,\delta^V\,(\delta^V + \delta^E))^2}\,\epsilon_t^2$	$L_t^{CB} = 0$

speculators may be a deliberate part of the intervention strategy. In order to keep away from the suboptimal Nash equilibrium the central bank may try to prevent speculators from learning the exact shape of its objective function.

The loss function in equation (7.36) reflects the central bank's aversion to non-fundamental exchange rate changes. However, it does not take account of the fact that in some instances the central bank may perceive large exchange rate changes to be less harmful than in other instances. For example, when the level of the exchange rate is broadly in line with the economic fundamentals of the domestic and foreign economy the central bank's weight to exchange rate stability may be low. An additional complicating factor is that the fundamentals themselves may change over time. Furthermore, the weight to exchange rate stability may depend on the central bank's perception of the strength of the underlying trend in the exchange rate. When the vast majority of private exchange market participants has a firm belief about the future course of the exchange rate the central bank is not likely to engage in intervention even if this exchange rate pattern is out of line with what it regards as desirable. Under these circumstances, the chance of turning around the market sentiment is small. At the same time, the chance of losing money with official operations in foreign exchange is large. Finally, as put forward by Cukierman (1992, pp. 161—2) the central bank's preferences may change to accommodate changes in the social and political pressures it feels. Apparently, Cukierman assumes that the central bank is unable to withstand these pressures because of lacking political independence.

Cukierman and Meltzer (1986) analyse the consequences of shifting objectives of the monetary authorities in a monetary policy game. Analogous to their approach, changing objectives in the exchange rate policy game can be captured by specifying α as a stochastic variable with the following characteristics:

$$\begin{aligned} &\alpha_t = A + p_t, && A > 0 \\ &p_t = \rho p_{t-1} + v_t, && 0 \le \rho \le 1 \\ &v_t \sim N(0, \sigma_v^2) && \end{aligned} \qquad (7.40)$$

where A is the mean, publicly known, value of α_t. The term p_t is the stochastic component of policymaker preferences.

Clearly, shifting objectives of the central bank *per se* do not imply a deviation from the symmetric information Nash equilibrium. In the present exchange rate policy game, when private speculators know the realizations of α_t at the beginning of period t, they still can calculate the volume of intervention the central bank will carry out in response to their setting of INV_t^e. What results is the suboptimal Nash equilibrium as derived in equation (7.31) whereby different realizations of α_t lead to different values for the optimal amount of intervention.

Things become different if the policymaker has private information about his own preferences. For instance, this is the case if in period t the realization of α_t (or p_t) is known by the central bank but not by the public. The central bank is as ignorant as the speculators about future innovations υ to the central bank's objectives. However, based on its knowledge of the current value of α_t (or p_t), the central bank can produce a more precise forecast of future values of α_t than the speculators. Cukierman and Meltzer (1986) ingeniously introduce a learning process for individuals in the monetary policy game. Their argument can be applied straightforwardly to the exchange rate policy game.

Suppose speculators know the stochastic structure of the process which leads to changes in α_t, that is, suppose that they know the values of σ_υ^2 and ρ. Assume, in addition, that speculators obtain a precise observation on p_{t-2} at the beginning of period t prior to their position taking on the foreign exchange market in that period. At the same time, initially they remain ignorant about p_{t-1}. However, they know that p is serially correlated according to equation (7.40). Moreover, the volume of intervention in period t—1 contains information about the value of p_{t-1}. Consequently, speculators will use INV_{t-1}, the volume of intervention in period t—1, to update their forecast of period t's volume intervention.

The very fact that learning becomes an important feature of the behaviour of speculators has important consequences for exchange rate policy. Learning, essentially introduced by the assumption that the central bank has private information about its own preferences, causes current decisions of the central bank on the volume of intervention to affect the expectation of speculators regarding the next period's volume of intervention. As was the case in the static exchange rate policy game analysed above (see equation (7.29)), the central bank will feel the need to at least partially accommodate expected interventions. However, when an intertemporal policy loss function like in equation (7.36) applies, the central bank takes into consideration the adverse effect of its current action on the next period's losses. A higher actual volume of intervention in period t leads to a higher expected volume of intervention in consecutive periods. Through the accommodation of expectations the actual volume of intervention in later periods rises too. The costs involved in intervening prevent the central bank from choosing the same volume of intervention as under complete information.

Cukierman and Meltzer assume that policymakers do not have perfect control over the rate of monetary growth. They postulate an identically and independently distributed random monetary control error. By assumption, the realization of this control error is not in the information set of the central bank when it determines the planned rate of monetary growth. However, the variance of the control error in the money supply process is publicly known. It appears to be an important parameter. When it is very large the latest money growth figures contain relatively little information about the changing objectives of the central bank. As a consequence rational individuals, who are assumed to know the variance of the monetary control error exactly, will not pay much attention to past inflation in forecasting the upcoming rate of inflation. It follows that the disciplining effect of learning is reduced and the rate of inflation actually chosen by the central bank will approximate the rate under symmetric information.

Imperfect control of the central bank's instrument is also an issue in the present exchange rate policy game. Foreign exchange interventions are the sole instrument of the central bank in the exchange rate policy game. The central bank tries to stabilize the exchange rate by means of surprise interventions. In fact, the unexpected part of an intervention is equal to the difference between the volume of intervention the central bank is reported to have carried out *ex post* (INV_t^R) and the *ex ante* expected volume of intervention (INV_t^e). However, central banks do not have perfect control over the volume of intervention that is reported in the financial press.[29] The relation between actual (INV_t) and reported (INV_t^R) intervention can be represented as follows

$$INV_t^R = INV_t + \psi_t, \qquad \psi_t \sim N(0, \sigma_\psi^2) \tag{7.41}$$

where ψ_t is a random intervention control error representing the central bank's inability to perfectly control the information speculators obtain about the volume of intervention.

For the monetary policy game Cukierman (1992, p. 175) shows that the inflationary bias disappears completely when σ_ψ^2 tends to zero and if, in addition, $\rho = \beta = 1$. There seems to be no reason why this result would not carry over to the intervention bias in the exchange rate policy game. Thus, the equilibrium volume of intervention is equal to zero when three conditions are met. Firstly, the central bank has perfect control over the volume of intervention that is reported in the financial press. Secondly, the central bank cares about the future as much as it cares about the present ($\beta=1$). The equal weighing of current benefits and future losses in the intertemporal loss function (7.36) reduces the likelihood of the central bank engaging in unexpectedly large intervention operations. Thirdly, the stochastic component of the central bank's preferences exhibits hysteresis (ρ = 1). The second condition implies that the central bank does not feel tempted to engage in surprise interventions because it weighs the short-term benefits and the long-term costs equally. The third condition implies that past volumes of intervention are very informative for predicting the current volume. This encourages speculators to carefully track the intervention record of the central bank. In turn, this diminishes the room for surprise interventions.

Every central bank may wish to have some room for influencing the course of the exchange rate. On the assumption that only unexpected interventions are effective, central banks have an interest in maintaining a positive value of the intervention control parameter σ_ψ^2. This is because the larger the variance of the intervention control error the harder it is for private exchange market participants to distinguish between changes in the volume of reported intervention brought about by persistent changes in the objectives of the central bank (υ_t) and those caused by transitory control errors (ψ_t). The public knows the average variability of υ and ψ. However, when only or mainly υ_{t-1} is responsible for an increase in INV_{t-1}, speculators underpredict it. This underprediction enables the central bank to alter the course of the exchange rate. Furthermore, when σ^2_ψ is high speculators pay little attention to past volumes of intervention. As a result the effect of the current volume of intervention on future expectations is small. This makes the future cost to the central bank of current intervention small too.

In order to let interventions have some leverage on speculators' behaviour their announcement effect has to be maximized. Consequently, central banks sometimes carry out highly visible interventions. At the same time, to be able to reap the benefits from their information advantage over speculators, central banks have an interest in preventing the financial press from giving exact reports on the incidence and volume of intervention. In other words, it is beneficial for the central bank to maintain some degree of ambiguity regarding (shocks to) its preferences and, hence, regarding the exact volume of intervention. The general refusal of central banks to release detailed up-to-date intervention data seems to be a practical implication of this.

Cukierman and Meltzer assume that individuals in the private sector only use past observations of money growth to predict present money growth. Balke and Haslag (1992) generalize their model. They allow individuals to 'purchase' additional information about innovations in the policymaker's preferences. Balke and Haslag assume that the more resources agents spent on information acquisition ('central bank watching'), the more precise are their estimates of the preference innovation (σ_v^2 is lower). As a result agents place less weight on past realizations of money growth and the central bank loses (some of) its information advantage. Obviously, the central bank will try to safeguard its information advantage over the private sector. One way of doing that is to increase the variance of the money control error. However, Balke and Haslag show that this is not very effective; it merely induces more intense central bank watching on the part of the private sector. From their analysis it follows that the monetary authorities should be more secretive. That increases the private sector's marginal cost of acquiring information about the authorities' shifting objectives and thus decreases the intensity of central bank watching.

Information is a highly valuable resource in the foreign exchange market. Private exchange market participants are very eager to detect changes in the objectives of the central bank. At the same time, the central bank requires an information advantage to render interventions effective. Two crucial implications for the exchange rate policy game can be derived from Balke and Haslag's generalization of the original 1986 Cukierman and Meltzer article. First, a necessary condition for maintaining the information advantage of the central bank in the exchange rate policy game is that the variance of the intervention control error is larger than zero. This translates into the requirement that the public is by no means able to acquire detailed and up-to-date actual intervention data. Otherwise, private exchange market participants would spend the necessary amount of resources to get access to the intervention data. Second, the central bank has to be very careful with public statements about the stance of exchange rate policy. Speculators are willing to devote a lot of efforts to interpret these statements in order to extract information about the central bank's shifting objectives. Central bank watching is intensified up to the point where the marginal gain of an improvement of their estimate of v_t exceeds the marginal costs of information acquisition. Public statements may thus undermine the effectiveness of interventions.

Obviously, public statements by (monetary) authorities may also be a deliberate part of exchange rate policy. The authorities may for instance try to 'talk down' the value of a currency. In the latter case, the aim is to actively use the eagerness of exchange market participants to detect information about changing policy objectives. However, there is an abundance of anecdotal evidence pointing at the problems with these public statements. Often they are misinterpreted by the financial press, leading to confusion rather than clarity.

Reasoning along the lines of the Cukierman and Meltzer (1986) model, it turned out to be beneficial for the central bank to maintain some degree of ambiguity regarding the exact volume of intervention. Analogously, Bhattacharya and Weller (1992) develop a theoretical explanation of why central banks do not make precise announcements of their exchange rate targets. Bhattacharya and Weller assume that the central bank 'leans against the wind' in the sense that it seeks to stabilize the spot rate around a target. This target may be inconsistent with exchange market fundamentals in the short run. As before, it is assumed that the central bank seeks to balance expected losses on exchange market transactions against its success in achieving its targeting objective. Bhattacharya and Weller recognize that the typical size of daily intervention is very small relative to the total volume of trade on the foreign exchange market. However, they argue that the central bank is not just another market participant. Rather, it should be viewed as an 'informed insider' in the foreign exchange market. Moreover, compared to the many individual private exchange market participants, the central bank is a large player in the market. Therefore, it is able to use its inside information about its own exchange rate target to limit the costs it incurs during interventions.

Bhattacharya and Weller assume that the central bank has more information about its own target than the private sector and that it acts strategically. They find that only when the central bank does not reveal its target to the market is sterilized intervention effective. This is because if the central bank does reveal its target, speculators no longer face any uncertainty about the next period's spot rate (S_1). Consequently, speculators will take unbounded positions in the forward market unless the current one-period forward rate (F_0) is equal to S_1. This implies that the central bank loses all ability to manipulate the exchange rate.

As long as the central bank's target exchange rate is not known exactly, intervention reveals information to the market. Bhattacharya and Weller show that for certain parameter values in their model relatively small interventions have a significant impact upon the spot exchange rate. The market-clearing condition for the forward market takes the form

$$Q^B + Q^S(S_0) = 0 \tag{7.42}$$

The aggregate speculative demand function takes the form

$$-Q^S = a_1 + a_2 S_0 + a_3 \epsilon_3 \tag{7.43}$$

where

Q^B = the quantity of forward foreign exchange purchased by the central bank

Q^S = the quantity of forward foreign exchange purchased by private speculators

ϵ_t = a random variable which denotes the fundamentals.

Bhattacharya and Weller analyse the characteristics of a_2 as a function of the speculators' precision on the distribution of the target exchange rate. The features to note are as follows:

> First, as the precision approaches zero, a_2 approaches a positive limiting value. Second, a_2 is monotonically declining in the precision. Third, as the speculators' precision on the distribution of the target exchange rate approaches infinity, a_2 approaches a limiting value which may be positive or negative, depending upon parameter values. (Bhattacharya and Weller 1992, p. 14)

Clearly, if a_2 is close to zero, relatively small interventions will have a significant impact upon the spot exchange rate. Moreover, a_2 — the market response to central bank intervention — can have either sign.

Bhattacharya and Weller establish that speculators always revise upwards their conditional expectation of the future spot rate in response to an increase in the current spot rate. However, the covered interest parity condition implies that, with the domestic and the foreign interest rate assumed constant, an increase in the current spot rate leads to an equal increase in the current forward rate.[30] Referring to equation (7.7) it can easily be seen that an increase in the conditional expectation of the next period's spot rate only leads speculators to buy in the forward market if this increase exceeds the impact of the change in S_0 on the forward rate F_0. If it does a_2 is negative. If it does not a_2 is positive.[31]

In Chapter 6 distinct periods were identified over which the spot exchange rate moved in opposite directions in response to intervention. Bhattacharya and Weller's theoretical result is consistent with these empirical findings. It also gives an indication of the causal factors involved.

7.6 CONCLUSIONS

This chapter is a first attempt to develop a positive theory of central bank intervention. Initially, an exchange rate policy game is analysed under symmetric information. The central bank is assumed to systematically resist realized shocks to the exchange rate. It is shown how the implied intervention behaviour in combination with the strategic interaction among the central bank and private speculators creates an 'intervention bias'. This bias is found to increase with the central bank's aversion to non-fundamental exchange rate changes. In the Nash equilibrium of the game a nonzero shock to the exchange rate induces a nonzero volume of intervention. However, the interventions are fully anticipated. Consequently, the interventions can not reduce the impact of shocks to the exchange rate through the expectations channel.

A dynamic extension of the exchange rate policy game with symmetric information does not lead to a more favourable picture regarding the central bank's ability to limit exchange rate changes around PPP. It is shown in the paper that the intervention bias disappears when the central bank, presumably by virtue of its political independence, acts as a Stackelberg leader in the exchange rate policy game. Stackelberg leadership, however, does not turn foreign exchange intervention working through the expectations channel into an instrument which is effective in equilibrium. It appears that a central bank can make interventions have some leverage on the exchange rate by maintaining an information advantage over the private sector concerning changes in its own objectives and by conserving a certain difference between the actual volume of intervention reported in the financial press.

APPENDIX A7.1 A STANDARD STATIC MONETARY POLICY GAME

Following Kydland and Prescott (1977), Barro and Gordon (1983a,b) and Milesi-Ferretti (1993) this appendix sets out the standard static monetary policy game between workers who sign wage contracts and the monetary authorities who implement monetary policy. The aim of this appendix is to derive expressions for the optimal time-consistent monetary policy in the domestic and foreign economy. In Section 7.4.2 it is assumed that private exchange market participants recognize that the underlying trend in the exchange rate is determined by PPP considerations. Clearly, based on the assumption that they have at least the same information as trade unions at home and abroad, they can compute the expected inflation rate for the domestic and the foreign economy and, hence, the expected PPP-implied change in the exchange rate. The latter is equal to the difference between the expected value of the time-consistent rate of inflation in the domestic and the foreign country (equation (7.25) in the main text).

An open economy with a floating exchange rate produces one homogeneous good whose price is determined on world markets. Domestic output y_t is determined by a 'Lucas supply curve' relation:[32]

$$y_t = y^M + \lambda(p_t - w_t) + \mu_t \qquad E_{t-1}\,\mu_t = 0;\ E_{t-1}\,\mu_t^2 = \sigma_\mu^{\ 2} \qquad \text{(A7.1)}$$

All variables are expressed in natural logarithms. y^M is the market-clearing level of output, p_t is the domestic price level, w_t is the nominal wage, μ_t is a supply shock and E_{t-1} is the operator of rational expectations based on information available at time t—1. Domestic output y_t will be above its market-clearing level y^M if real wages in the domestic economy fall or if the supply shock μ_t takes a positive value.

The timing of events in the monetary policy game is as follows: first, workers sign wage contracts based on their rational expectation of period t's inflation rate; second, the supply shock is observed; finally, the monetary authorities choose monetary policy and production takes place.

Table A7.1 Timing of events in a monetary policy game

Stage 1	Stage 2	Stage 3
Workers sign wage contracts based on $E_{t-1}\,\pi_t$	Supply shock μ_t is observed	Authorities choose rate of inflation $\hat{\pi}_t$

Workers attempt to maintain a constant level of the real wage, which is normalized to zero for simplicity:

$$w_t = E_{t-1}\, p_t \tag{A7.2}$$

Because of the timing assumption, the 'information set' of workers includes the structure of production and of monetary authorities' preferences, but does not include the realization of the supply shock.

Suppose existing distortions make the market-clearing level of output y^M lower than its socially optimal level ky^M, as in Barro and Gordon (1983b).[33] The preferences of the monetary authorities are described by a standard quadratic loss function:

$$L_t = \frac{1}{2}\,\pi_t^2 + \frac{\theta}{2}(y_t - ky^M)^2 \qquad k > 1 \tag{A7.3}$$

where π_t, equal to $p_t - p_{t-1}$, is the inflation rate. Equation (A7.3) implies that the optimal rate of inflation is zero.

The monetary authorities are unable to commit themselves to a given rate of inflation before wage contracts are signed. They therefore choose the rate of inflation that minimizes the loss function (A7.3), taking wage contracts as given. Because the market-clearing level of output is too low, the monetary authorities have an incentive to reduce real wages by creating surprise inflation, in order to raise output. However, in equilibrium it cannot accomplish this in a systematic fashion. Also, the monetary authorities have a margin for stabilization of the supply shock before monetary policy is chosen. Minimizing (A7.3) subject to (A7.1) yields the following optimal inflation rate:

$$\pi_t = \frac{\theta\lambda^2}{1 + \theta\lambda^2}\, E_{t-1}\,\pi_t + \frac{\theta\lambda}{1 + \theta\lambda^2}\,(H - \mu_t) \tag{A7.4}$$

where $H = (k - 1)\, y^M$ and the expected rate of inflation $E_{t-1}\,\pi_t$ is equal to $E_{t-1}\,p_t - p_{t-1}$. The term H is the wedge between the desired level of output and the market-clearing level: it measures the incentive of the monetary authorities to create surprise inflation, and therefore the intensity of the time-inconsistency problem in domestic monetary policy.

Workers are assumed to have rational expectations. Since the monetary authorities' preferences are known, they will predict inflation using (A7.4) and they will ask for inflation compensation accordingly:

$$E_{t-1}\,\pi_t = \theta\lambda\,H \tag{A7.5}$$

The time-consistent rate of inflation will therefore be given by:

$$\hat{\pi}_t = \theta\,\lambda\,H - \frac{\theta\lambda}{1 + \theta\lambda^2}\,\mu_t \tag{A7.6}$$

Clearly, apart from the term H, steady-state inflation also depends positively on both the weight assigned by the monetary authorities to raising domestic output to a desired level which is above the market-clearing level (θ) and the responsiveness of domestic output to decreases in the real wage (λ).

Analogously, the predicted rate of inflation for the foreign economy will be equal to

$$E_{t-1}\,\pi_t^* = \theta^*\lambda^*\,H^* \tag{A7.7}$$

Obviously, similar monetary policy games at home and abroad may lead to different expected rates of inflation and optimal time-consistent rates of inflation for the domestic and foreign economy. The responsiveness of output to changes in the real wage (λ), the difference between the market-clearing level of output and its socially optimal level (H) and/or monetary authorities' preferences (θ) may be different in any pair of countries (see, e.g. Cukierman 1992, p. 29).

It was assumed that private exchange market participants have at least the same information as trade unions at home and abroad. Therefore, they can compute the expected inflation rate for the domestic and the foreign economy and, hence, the expected PPP-implied change in the exchange rate. The latter is equal to the difference between the expected value of the time-consistent rate of inflation in the domestic and the foreign country:

$$E_{t-1}\,\Delta\,s_t = E_{t-1}\,\pi_t - E_{t-1}\,\pi_t^* = \theta\,\lambda\,H - \theta^*\,\lambda^*\,H^* \equiv a \tag{A7.8}$$

NOTES

1. According to Neumann (1984, p. 226) the flow model of the exchange rate analysed here 'is certainly close to the exchange market view of most policymakers'.
2. By assumption, the financial assets are denominated in domestic currency. One unit of domestic currency invested at the domestic interest rate i_t will have grown after one period to $(1+i_t)$, which, if converted into foreign currency at the spot rate S_{t+1}, is equal to $(1+i_t)/S_{t+1}$ units of foreign currency. The representative investor may as well opt to exchange his initial unit of domestic currency into foreign currency at the spot rate S_t at the beginning of the period. At the end of the period his investment will be worth $(1+i_t^*)/S_t$ units of foreign currency. Clearly, it is profitable to hold financial assets denominated in domestic currency as long as

$$\frac{1+i_t}{S_{t+1}} > \frac{1+i_t^*}{S_t} \Leftrightarrow \frac{1+i_t}{1+i_t^*} > \frac{S_{t+1}}{S_t} \quad \Leftrightarrow \frac{1+i_t}{1+i_t^*} - 1 > \frac{S_{t+1}}{S_t} - 1$$

$\Leftrightarrow \dfrac{i_t - i_t^*}{1+i_t^*} > \dfrac{S_{t+1} - S_t}{S_t}$. If i_t^* is small and $\dfrac{i_t - i_t^*}{1+i_t^*} \approx i_t - i_t^*$, this condition

simplifies to $i_t - i_t^* > \dfrac{S_{t+1} - S_t}{S_t}$, or, in logs $i_t - i_t^* > s_{t+1} - s_t$.

3. The following 'exchange rate equation' can be derived from (7.1) and (7.7):

$$s_t = s_{t-1} - \Delta\left[(i_t - i_t^*) - E_t\, s_{t+1}\right] + (INV_t - CA_t)\, \gamma\, Var\, s_t \tag{N7.1}$$

minimizing the loss function in (7.9) with respect to INV_t yields

$$\frac{\partial L_t^{CB}}{\partial INV_t} = 2\,(s_t - s_t^T)\,\frac{\partial s_t}{\partial INV_t} = 0 \quad \text{where} \quad \frac{\partial s_t}{\partial INV_t} = \gamma\, Var s_t \tag{N7.2}$$

Substituting equation (N7.1) into (N7.2) and solving for INV_t gives

$$INV_t = CA_t + \frac{1}{\gamma\, Var s_t}\left[\Delta(i_t - i_t^* - E_t s_{t+1}) - (s_{t-1} - s_t^T)\right] \tag{N7.3}$$

By definition, RP_t, the expected risk premium on assets denominated in domestic currency is equal to $RP_t = f_t - E_t\, s_{t+1}$, where f_t denotes the log of the one-period forward rate. After making use of the interest arbitrage condition, $i_t - i_t^* = f_t - s_t$, the first bracketed expression on the right-hand side of equation (N7.3) can be rewritten into

$$\Delta(i_t - i_t^* - E_t s_{t+1}) = \Delta(i_t - i_t^* + RP_t - f_t) = \Delta RP_t + \Delta s_t \tag{N7.4}$$

Substituting (N7.4) into (N7.3) yields (7.10).

4. For supporters of structural exchange rate models this may be a disappointing specification of the exchange rate equation. However, short-term exchange rate movements do not seem to be driven by fundamentals according to an identifiable relationship. The many forces working on exchange rates do not show a clear pattern and in sufficiently long samples they even out making the drift a equal to zero.
5. In economic terms this means that shocks to the exchange rate have a permanent effect.

In other words, the exchange rate does not return to its starting value after a shock has occurred.

6. Of course, it is possible that the factor $a + s_{t-1} - s_t^T$ on the one hand and the factor ϵ_t on the other hand embody opposite signals as to the direction of intervention. It is even possible that the central bank minimizes the value of its loss function by refraining from intervention. This is the case when $a + s_{t-1} - s_t^T = - \epsilon_t$.
7. To be sure, interventions in the DM/$ market are mostly conducted in the second half of the European Segment of the global foreign exchange market when both the European and US currency markets are open (Goodhart and Hesse 1993). Thus, period t could be defined as running from say 15.00 hours (Central European Time) on day t—1 to 15.00 hours (CET) on the next day the foreign exchange market is open.
8. The factor of proportionality for the costs of intervention, c, is exogenous in the present model. One can easily imagine, however, that the potential losses from intervention increase with the predictability of the actions of the central bank.
9. Only when the central bank assigns a sufficiently high weight to limiting exchange rate changes (high value of the coefficient α) is it not bothered by the costs of intervention and the reaction coefficient reduces to the one in (7.16). This follows directly from

$$\lim_{\alpha \to \infty} -\frac{\alpha\, \delta^V}{c^2 + \alpha\, (\delta^V)^2} = -\frac{1}{\delta^V}.$$

10. The partial derivative $\dfrac{\partial \dfrac{\alpha\, \delta^V}{c^2+\alpha(\delta^V)^2}}{\partial \delta^V} = \dfrac{\alpha\, (c^2-\alpha\, (\delta^V)^2)}{(c^2+\alpha\, (\delta^V)^2)^2} > 0$ as long as $(\delta^V)^2 < c^2/\alpha$.
11. The partial derivative $\dfrac{\partial \dfrac{\alpha\, \delta^V}{c^2+\alpha(\delta^V)^2}}{\partial \alpha} = \dfrac{\delta^V\, c^2}{(c^2+\alpha(\delta^V)^2)^2} > 0$ as we assumed that $\delta^V > 0$.
12. This section is based on Almekinders (1994b).
13. Some countries, like for instance Finland, Norway and Sweden, have indeed resorted to devaluation policies in the recent past. After the widening of the ERM bands on August 2, 1993 the intra-European exchange rates are allowed to deviate 15 per cent on either side from their central parities. Many proponents of exchange rate stability feared that some European monetary authorities would engage in competitive devaluations of their currencies. However, exchange rates remained remarkably stable. Apparently the monetary authorities foresaw that private investors would respond to devaluations by demanding a higher return on investments denominated in the weaker currencies thereby raising (long-term) interest rates at a time when there was a perceived need to lower them drastically.
14. Article IV of the Articles of Agreement of the IMF provides that 'a member shall ... avoid manipulating exchange rates or the international monetary system in order to prevent effective balance of payments adjustment or to gain an unfair competitive advantage over other members' (IMF 1993, p. 5).
15. In a Nash equilibrium neither of the players can improve on his own situation given the action of the other player.
16. The shock to the exchange rate may exhibit persistence according to $\epsilon_t = \epsilon_{t-1} + b + \chi_t$, where χ_t is a normally distributed random variable with mean zero and variance σ_χ^2 and b, the drift of the ϵ-process, is the constant and predictable part of the shock. In this section the exact specification of the shock is not important as speculators are supposed to form expectations after its realization.
17. What stands out from Dominguez and Frankel (1993a, Figures 5.1 and 5.4—5.13) is that the Bundesbank, the Federal Reserve and the Swiss National Bank refrain from intervening on the majority of trading days. More importantly, typical intervention

efforts by these central banks are of the order of \$100 to \$300 million. In April 1992, the daily average of global spot market turnover net of double-counting arising from both local and cross-border interbank operations was estimated to be \$400 billion. This implies a 15 per cent rise from the corresponding estimate of \$350 billion for April 1989 (Bank for International Settlements 1993).

18. Chapter 2 illustrates how intervention operations that, for example, increase the current relative supply of German mark to US dollar assets which private investors are obliged to accept into their portfolios, force a decrease in the price of German mark assets.
19. It can easily be seen from equation (7.25) that the effect of (unexpected) interventions in support of the foreign currency may not be large enough to *fully* compensate for the downward pressure on the exchange rate, i.e. when

$$0 < \delta^V INV_t + \delta^E (INV_t - INV_t^e) < |a + \epsilon_t| .$$

In that case, casual observation of the resulting exchange rate movement, Δs_t, leads one to conclude that the interventions were not effective. This touches upon the familiar methodological problem that, in practice, the rate of appreciation $a + \epsilon_t$ that would have occurred in the absence of intervention is not known.

20. In Krugman's (1991) target zone model the anticipation of unlimited *unsterilized* interventions by the central bank at the edges of the band induces an S-shaped exchange rate pattern inside the band, the so-called honeymoon effect. There is no such effect in the model here. This is because the central bank is assumed to use monetary policy instruments only for domestic policy objectives. This assumption, which seems realistic for most large industrialized countries, diminishes the scope for central bank intervention rather dramatically. Private speculators know that interventions have no significant impact on the exchange rate as long as they do not come by surprise. Hence the absence of a honeymoon effect.
21. Blackburn and Christensen (1989, p. 12) address issues of intra-private sector behaviour in a general game-theoretic context.
22. $\dfrac{\alpha\delta^E(\delta^V+\delta^E)}{c^2+\alpha(\delta^V+\delta^E)^2} < 1$ as long as $c^2 > -\alpha\,\delta^V(\delta^V + \delta^E)$. This holds by assumption.
23. This figure is based on a similar one in Blanchard and Fischer (1989, p. 597).
24. At points to the left (right) of N, the private sector chooses INV_t^e and the central bank responds by actually carrying out INV_t such that $INV_t > INV_t^e$ ($INV_t < INV_t^e$).
25. It can be shown that the reaction coefficient in (7.23) is smaller in absolute value than the one in (7.31), i.e. $\dfrac{\alpha\delta^V}{c^2+\alpha(\delta^V)^2} < \dfrac{\alpha(\delta^V+\delta^E)}{c^2+\alpha\delta^V(\delta^V+\delta^E)}$, if $c^2\,\alpha\,\delta^E > 0$ which is true by assumption.
26. It can be shown that the value of the loss function in (7.33) is larger than the one in (7.24) if $\delta^E > 0$ which is true by assumption.
27. Eijffinger and Schaling (1993a) show that the Alesina (1988, 1989) synthetic indicator of central bank independence is internally inconsistent and does not qualify as an index. Grilli, Masciandaro and Tabellini (GMT) (1991) develop an index of political and economic independence which is very broad. Because they use eight criteria in determining the degree of independence, it can be argued that the essential characteristics of central bank independence are watered down. Alesina and Summers (1993) average the Alesina index and the GMT index of political and economic independence.
28. Al-Nowaihi and Levine (1994) provide a resolution of the non-uniqueness of reputational equilibria in the Barro—Gordon model.
29. Klein (1993) and Osterberg and Wetmore Humes (1993) show that there are systematic and significant differences between daily volumes of intervention actually carried out by the Federal Reserve and those reported in the financial press. Klein found that the

likelihood of intervention being reported given that it actually occurred was 72 per cent and that the likelihood of intervention actually occurring given that it was reported was 88 per cent.

30. Sterilized intervention operations usually lead to changes in interest rates at home and abroad. However, the authors focus on the effect of small but informative interventions. Therefore, the assumption of constant interest rates is not very restrictive.
31. For a critical set of parameter values a_2 can be zero. In that case speculative positions in the forward market are independent of the spot rate and the spot rate is indeterminate.
32. Argy (1992) sets out how equation (A7.1) is derived.
33. After reviewing many studies Blackburn and Christensen (1989, p. 10) conclude that 'these distortions are usually alleged to arise from the existence of taxes and transfers (in particular, income taxation and unemployment compensation), but could also reflect the presence of trade unions or minimum wage laws that prevent voluntary decisions over work and leisure'.

8. Summary and Concluding Remarks

In principle, exchange rate stability is a public good. However, since the demise of the Bretton Woods system of fixed exchange rates the exchange rates of the major currencies have been highly volatile. To comply with Article I of the Articles of Agreement of the International Monetary Fund as amended in 1992 central banks are obliged to promote a stable exchange rate system and hence to 'counter disorderly exchange market conditions'. It is often argued that closer coordination and cooperation among countries on monetary and fiscal policies would reduce fluctuations in exchange rates and hence foster economic growth. However, in general, the monetary and fiscal authorities of large industrial countries give priority to domestic policy objectives.

Chapter 1 of this book describes the exact implications of an operation in foreign exchange carried out by the domestic central bank to change the exchange rate of the domestic currency *vis-à-vis* one or more foreign currencies. It appears that an official purchase of foreign currency conducted to curb an appreciation of the domestic currency eventually leads to an increase in the domestic money stock. In Chapter 2 it turns out that this increase in the domestic money supply in itself is very conducive to limiting the rise in the value of the domestic currency. However, the monetary authorities of most large countries do not want exchange rate policy to interfere with monetary policy. Consequently, central banks routinely neutralize the money-market effect of their interventions in the foreign exchange market. At first sight, the resulting sterilized interventions allow the central banks to strike a perfect balance between trying to limit exchange rate fluctuations on the one hand and pursuing an independent monetary policy on the other hand. However, the crucial question which comes up is: are sterilized interventions effective? The theoretical models surveyed in Chapter 2 imply that the potential effectiveness of sterilized interventions depends very much on the efficiency of the foreign exchange market. Earlier models usually assume that the foreign exchange market is efficient in the sense that market participants use some structural model as a yardstick when taking positions on the foreign exchange market. Chapter 2 makes clear that in these models sterilized intervention can only be effective when risk-averse investors believe assets denominated in different currencies to have different risk characteristics. In that case, a swap of domestic bonds for foreign bonds in the portfolio of the private sector brought about by a sterilized purchase of foreign currency by the domestic central bank can lead to an appreciation of foreign currency. However, the empirical studies surveyed in Chapter 3 do not find a systematic effect of sterilized intervention through the so-called portfolio balance channel. Moreover, the scale of intervention relative to the magnitude of flows in the foreign exchange market and relative to the magnitude of stocks of private foreign assets is insignificant. Therefore, on the basis of casual empiricism the potential for central banks to cause a significant imbalance in investors' portfolios seems negligible.

Chapter 2 does suggest that the scope for intervention changes quite dramatically when one is willing to drop the assumption that the foreign exchange market is efficient in the sense that market participants base trading in the foreign exchange market on some structural model. However, the literature on how the inefficiency of the foreign exchange market opens up distinct channels through which intervention can affect the exchange rate is still in its infancy. Some of the empirical studies surveyed in Chapter 3 suggest that official exchange market operations which create expectations of changes in monetary policy or which embody another sufficient 'news'-content appear to have a chance of affecting the exchange rate significantly.

It is a fact of observation that central banks intervene in case of strains on the foreign exchange markets. Moreover, the insights presented thus far do not rule the possibility that out that sterilized interventions can affect the exchange rate. Chapters 4 to 6 report on the results of original empirical investigations into the objectives and effectiveness of interventions conducted by the Bundesbank and the Federal Reserve System. These investigations were made possible by the availability of daily intervention data of the Bundesbank and the Federal Reserve System in the Deutsche Mark/US dollar market and the Japanese yen/US dollar market.

Chapters 4—6 abandon the traditional structural exchange rate models. The failure of these models in empirical tests is well documented in the literature. Discontent with the performance of structural exchange rate models in explaining the actual behaviour of exchange rates has led many economists to adopt new research strategies in exploring the field of exchange rate economics. Within a short time an extensive literature has developed which studies the statistical properties of short-term returns in the foreign exchange market and other financial markets. The purport of this so-called GARCH literature is that volatility in daily returns is predictable in most financial markets. In several applications it has been shown that there is a considerable persistence in the effects of shocks in one period onto the conditional variance of exchange rates in consecutive periods. The material in Chapters 4 and 5 is novel because it incorporates the insights derived from the GARCH literature into the decision-making process of the central bank. It is well known that the establishment of the Plaza Agreement of September 22, 1985 marked the beginning of enhanced coordination of exchange rate policies among the G-7 countries. Chapter 4 shows that a GARCH model for the exchange rate can capture the stabilizing effect of the policy coordination on the course of the Deutsche Mark US dollar exchange rate. More importantly, the Bundesbank and the US Federal Reserve System are found to have taken account of the predictability of volatility when they intervened in the foreign exchange market over the post-Louvre period February 23, 1987 to October 1989. The estimation results presented in Chapter 4 indicate that both the Bundesbank and the Federal Reserve System conducted their official foreign exchange operations consistently. Both central banks appear to have tried to counter 'disorderly market conditions' from day to day. A 'leaning against the wind' policy appears to have prevailed across four post-Louvre subsamples of at least three months. The estimation results presented in Chapter 5 suggest that both the Bundesbank and the Federal Reserve tried to counteract appreciations of their own currency more strongly than depreciations. After having established that both central banks conducted their interventions consistently, it is straightforward to ask the question whether these interventions were effective. It is well known that there are a lot of problems involved in estimating the effectiveness of interventions. Chapter 6 makes two contributions to understanding and testing the effectiveness of central bank interventions. Firstly, the simultaneity problem between exchange rates and interventions is addressed explicitly. Secondly, the direct effect of intervention on the level of the exchange rate is estimated. The estimation results presented in Chapter 6 indicate that, in general, interventions conducted by the Bundesbank and the Federal Reserve System were not successful at systematically reversing unwanted movements in the DM/$ and the ¥/$ exchange rate. What it does imply is that there is no time-invariant one-to-one relationship with interventions causing exchange rate movements. This confirms the intuition of many private exchange market participants and central bankers who manage the Foreign Exchange Trading Desk. The lack of a systematic effect of interventions does not rule out the possibility that private exchange market participants may sometimes be caught off balance by the news of central banks entering the market. This insight serves as a starting point to develop a positive theory of central bank intervention.

Chapter 7 uses the insights derived from the recent game-theoretic approach to monetary and fiscal policy. Account is taken of the fact that regular central bank transactions in foreign exchange are very small compared to the daily turnover on the global foreign exchange market. In Chapter 7 it is argued that the introduction of strategic behaviour by central banks can alter the scope for intervention dramatically. This chapter analyses a simple exchange rate policy game between a central bank and rational speculators under symmetric information. The central bank tries to counteract shocks to the exchange rate by means of sterilized intervention working through the expectations channel. Private speculators resist being fooled. They anticipate the interventions. An 'intervention bias' results with an inefficiently high equilibrium volume of intervention which does not reduce the impact of shocks to the exchange rate. Cross-country evidence lends support to the propositions derived from the model that the more independent the central bank the smaller and the more consistent the intervention efforts. This suggests that countries should make their intervening authority independent from politicians. This is a new result which complements the findings of the topical literature on the political economy of central bank independence which has been growing out of the game-theoretic approach to monetary policy. A second finding relates to the general refusal of central banks to release detailed-up-to date intervention data. In the framework of a game with asymmetric information it turns out to be beneficial for the central bank to maintain some degree of ambiguity regarding (shocks to) its preferences and, hence, regarding the exact volume of intervention. Official operations in foreign exchange only have a chance of affecting the exchange rate if they convey new information to private market participants regarding changes in the objectives of the central bank. This is the case if the private sector has less information about shifting objectives of the central bank. The central bank can conserve its information advantage by not releasing exact intervention data.

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Summary in Dutch

Samenvatting

In 1973 viel het Bretton Woods systeem van vaste wisselkoersen uit elkaar. Sindsdien is er in principe sprake van vrij zwevende wisselkoersen. Regelmatig valt echter waar te nemen dat een of meer centrale banken de prijsvorming op de valutamarkten trachten te beinvloeden door middel van aan- of verkopen van vreemde valuta's. Dergelijke transacties worden valutamarktinterventies genoemd. Dit proefschrift onderzoekt de doelstellingen en effectiviteit van valutamarktinterventies en tracht een antwoord te vinden op de vraag waarom centrale banken blijven intervenieren terwijl hun acties over het algemeen geen effect lijken te hebben.

Hoofdstuk 1 geeft een exacte definitie van een interventie en bespreekt de effecten van een interventie. Een initiële interventie waarvan het geldmarkt effect wordt geneutraliseerd wordt een gesteriliseerde interventie genoemd. Hoofdstuk 2 analyseert het effect van interventies binnen het kader van gangbare wisselkoersmodellen. Het blijkt dat in theorie ook gesteriliseerde interventies effect kunnen hebben op de wisselkoers. Hoofdstuk 3 geeft een overzicht van de resultaten van het empirisch onderzoek dat sinds 1973 is uitgevoerd naar de doelstellingen en effectiviteit van valutamarktinterventies. De meeste studies vinden dat centrale banken consistent en systematisch interveniëren. In veel gevallen blijken de centrale banken een 'leaning against the wind'-beleid te hebben gevoerd. Dit houdt in dat de centrale banken tegen de koersbeweging in handelen (vreemde valuta's verkopen (kopen) als de koers van deze valuta's stijgt (daalt)). Het is de bedoeling om daarmee het koersverloop te stabiliseren. Echter, bestaand empirisch onderzoek concludeert over het algemeen dat gesteriliseerde interventies geen systematisch effect op het wisselkoerverloop hebben. Eigen empirisch onderzoek beschreven in de Hoofdstukken 4 tot en met 6 bevestigt deze inzichten. Dit onderzoek maakt gebruik van dagcijfers voor valutamarktinterventies van de Deutsche Bundesbank en het Federal Reserve System. De beschikbaarheid van dagcijfers maakt het mogelijk de korte-termijn doelstellingen en effectiviteit van interventies te onderzoeken. In de

Hoofdstukken 4 tot en met 6 wordt daarbij gebruik gemaakt van recente inzichten uit de financieringsliteratuur. Deze literatuur besteedt veel aandacht aan het fenomeen dat dagelijkse koersschommelingen op financiële markten een patroon te zien geven van clusters van hoge 'returns' afgewisseld door relatief rustige perioden. Dit maakt dat de volatiliteit van financiele markten tot op zekere hoogte voorspelbaar is. Met andere woorden, als het vandaag rustig is op de wereldvalutamarkt is de kans groot dat er ook morgen slechts kleine wisselkoerveranderingen vallen te noteren. Als het vandaag hectisch is zal er naar verwachting ook morgen veel turbulentie zijn. De resultaten van het empirisch onderzoek in Hoofdstuk 4 en 5 geeft aan dat de Bundesbank en de Federal Reserve gebruik maken van de voorspelbaarheid van de variantie van wisselkoersen. Naast korte-termijn 'leaning against the wind'-gedrag blijken de centrale banken ook te intervenieren in reactie op een stijging van de conditionele variantie van de Duitse Mark/Amerikaanse dollar-koers.

In Hoofdstuk 6 wordt gebruik gemaakt van een adequate econometrische techniek om de korte-termijn effectiviteit van interventies vast te stellen. Voor de onderzochte steekproefperioden in het tijdvak februari 1987-oktober 1989 blijkt dat de interventies van de Bundesbank en de Federal Reserve geen systematisch effect hebben gehad op de DM/$-koers.

Uiteraard doen deze resultaten de vraag rijzen waarom centrale banken nog intervenieren. Hoofdstuk 7 tracht deze vraag te beantwoorden. Een verklaring voor het waargenomen interventie gedrag kan worden gevonden in het feit dat centrale banken die niet volledig onafhankelijk mogen opereren van politici in het algemeen en het Ministerie van Financien in het bijzonder soms gedwongen worden om over te gaan tot interventies. Onder overigens gelijkblijvende (monetaire) omstandigheden zouden de interventies de wisselkoers moeten beïnvloeden door het publiek te verrassen.

De monetaire autoriteiten van grote landen zijn over het algemeen niet bereid om hun monetaire beleid ondergeschikt te maken aan hun wisselkoersbeleid. Interventies waarvan het geldmarkt effect wordt geneutraliseerd vormen echter door de bank genomen een vrij machteloos instrument dat niet in staat is tegenwicht te bieden aan de omvangrijke kapitaalstromen die door private valutamarktparticipanten worden gegenereerd. Gesteriliseerde interventies kunnen wel gebruikt worden om de private sector uit haar evenwicht te brengen. Transacties in vreemde valuta's zijn met veel onzekerheid omgeven. Met interventies kunnen centrale banken een signaal geven. Dit kan private valutamarkt-participanten aan het denken zetten over de duurzaamheid van het bestaande wisselkoersniveau. Dit kan hen aanzetten tot het zodanig afdekken van open posities dat de wisselkoers in de door de centrale bank gewenste richting gaat bewegen.

In Hoofdstuk 7 wordt gebruik gemaakt van de inzichten uit de moderne spel-theoretische benadering van monetaire en budgettaire politiek. Het blijkt dat ook de uitkomsten van de 'exchange rate policy game' tussen centrale bank en rationeel publiek aanleiding geven om te pleiten voor een zo groot mogelijke politieke en economische onafhankelijkheid van de centrale bank. Een politiek afhankelijke centrale bank kan gedwongen worden te interveniëren. Rationele private valutamarktparticipanten kennen de machtsverhoudingen en voorzien de interventies. Daarmee is het verrassingseffect van interventies tot nul gereduceerd. Wat resteert zijn de vrijwel onvermijdelijke verliezen voor de centrale bank. Een centrale bank die zelf mag weten wat ze doet en bovendien niet gedwongen is om volledige inzage te geven in de exacte interventiecijfers (asymmetrische informatie) blijkt het beste in staat om het wisselkoersverloop enigszins te stabiliseren.

Hoofdstuk 8 bevat conclusies.